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IDENTIFICATION OF ALTERNATIVE POWER SOURCES FOR DREDGED MATERIAL PROCESSING OPERATIONS.

by

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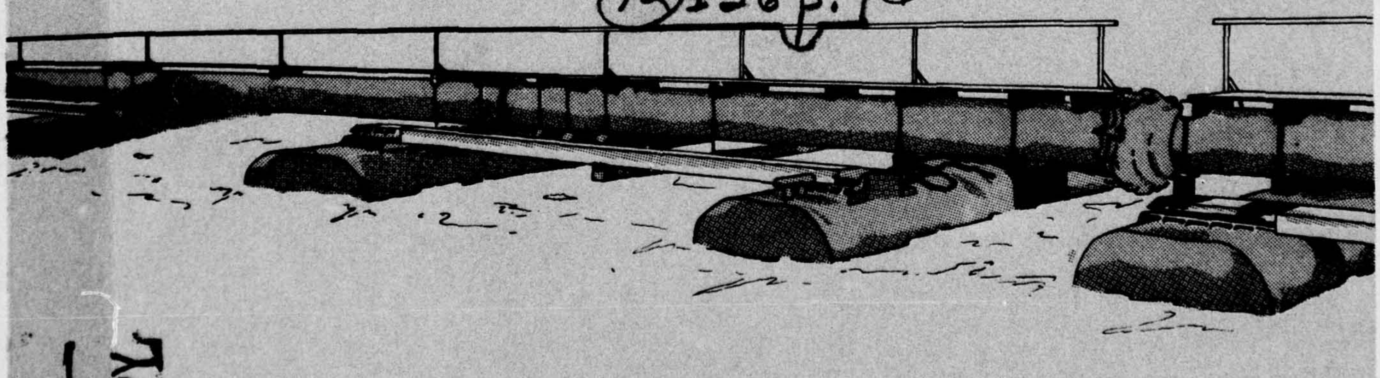

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SUBJECT: Transmittal of Technical Report D-77-32

TO: All Report Recipients

1. The report transmitted herewith represents the results of a research effort (work unit) initiated as part of Task 5C (Disposal Area Reuse Research) of the Corps of Engineers' Dredged Material Research Program (DMRP). Task 5C is included under the Disposal Operations Project, which is concerned with both the environmental effects of disposal operations and facilities as well as new concepts for disposal, particularly those concepts involving consideration of dredged material as a resource rather than simply a waste product.

2. A particularly attractive concept for mitigating the land requirements for disposal sites is to increase the life expectancy of sites through the periodic removal of dredged material for use elsewhere. Optimally, sites could be used indefinitely and be truly permanent disposal facilities. However, continuing needs for the dredged material must be identified; procedures must be identified for processing and/or rehandling materials; and mechanisms must be established for marketing materials under known constraints.

3. The investigation reported herein addresses identification of power sources for processing systems at reusable disposal sites. Processing systems at disposal sites may be designed to extract sand and gravel for commercial use, remove silt and clay from water to meet effluent-quality restrictions, and dewater residual silt and clay to reduce volume and/or provide a more desirable material. Conventional power may not be available or may be extremely expensive due to the remoteness and inaccessibility of many of the disposal sites; consequently, alternative power sources were investigated for the DMRP by the Civil Engineering Laboratory, Naval Construction Battalion Center, Port Hueneme, California.

4. The scope of the assigned task was to provide a screening and selection procedure for designing power sources for dredged material processing systems. No original research was conducted as part of this study, and conclusions were drawn based on existing information. The exact power requirements for reusable disposal sites are unknown because

this study was made concurrently with studies to provide guidance on the design of such facilities. However, the range of magnitude of power available from alternative sources was determined and could be fitted to the power requirements later.

5. Wind, solar, and hydraulic power sources were considered in the study. Results indicated that even though flat-plate solar collectors are now commercially available to heat air or water for buildings, they are not well adapted to known dredged material processing systems requirements. Solar cell electrical power generation, though available, is not cost competitive in its application at present. Likewise, hydraulic power generation by waves, currents, or small hydroelectric plants does not appear to be practical at typical dredging sites. Of all the alternative power sources studied, wind electric generation seemed to be the most practical and versatile.

6. Though the unit cost of wind-produced electricity is competitive, the present generator size limit of 12 kw might require a large number of wind-powered generators at a dredging site. For example, if windmills were used to power dewatering devices such as vacuum pumping or electroosmosis systems, approximately one 12-kw wind-powered generator would be needed for each acre. However, larger 100-kw wind-powered generators are now under operational tests. A typical 100-acre disposal site could be dewatered by devices operated by twelve 100-kw generators.

7. The results of this study will be included as part of a synthesis report on the concept of reusable disposal sites. Of course, the results are also applicable to any situation where power may be required at a disposal site.

JOHN L. CANNON
Colonel, Corps of Engineers
Commander and Director

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report provides a basis for selecting alternative, renewable power sources specifically for operating dredged material processing systems.

A dredged material processing system is designed to: (1) extract sand and gravel for commercial use, (2) remove silt and clay from water to meet quality restrictions on return water, and (3) dewater the residual silt and clay to reduce volume and provide a usable foundation for later land use. Currently, processing of dredged material usually consists of holding the hydraulically pumped slurry in a diked containment area and pumping or draining off the water after settlement of the suspended material. Subsequent natural drying by sun and wind presents a problem if the material is a fine-grained silt or clay.

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20. ABSTRACT (Continued).

The scope of the assigned task was to provide a screening and selection procedure for the engineer designing a dredged material processing system in order to decide which natural form of energy (or combination), if any, should be chosen to power the system. Power requirements of the mechanical gravel and sand separators would be established when specific equipment is selected for a particular system. Mobile equipment for dredged material processing might be powered from the alternative sources; for example, electric motors could operate on batteries charged by the alternative sources.

The exact power requirements to dewater the fine-grained fractions are unknown because dewatering equipment is presently under development, but alternative power can be provided in several forms. The following were considered in this study: (1) Wind power, driving pumps and electric generators, (2) Solar radiation converted to thermal and electrical energy, and (3) Hydraulic power (waves and currents) for driving electric generators. Some consideration was given to obtaining power from solid waste (such as incineration of trash), but was discarded as not pertinent to the scope of this report.

Even though flatplate solar collectors are now commercially available to heat air or water for buildings, they are not well adapted to known dredged material processing systems. Solar cell electrical power generation, though available, is not cost competitive in this application at present. Likewise, hydraulic power generation by waves, currents, or small hydroelectric plants does not appear to be practical at typical dredging sites.

Of all the alternative power sources studied, wind electric generation seems to be the most practical and versatile to apply at this time. A 12-kw DC wind generator is shown to provide power at Buffalo, New York (best site), for \$0.0243/kw-hr, a price actually less than the typical purchased electricity cost of \$0.0263/kw-hr. Electrical power could be used by the vacuum pumping and electro-osmotic dewatering systems presently under development elsewhere. Though the unit cost of wind-produced electricity is competitive, the present size limit of 12 kw might imply a large number of wind generators at dredging sites. Such a situation may be deemed impractical at this time.

With an estimate of 0.15 kw-hr to be required to remove 1 gallon of water from dredged material by electro-osmosis, the 12-kw wind generator could provide energy to dewater over 2500 cu yd of dredged material in a year at favorable locations. The energy cost for this processing would be \$0.18/cu yd. Vacuum well-point pumping is also being tested by other Dredged Material Research Program investigators using wind-generator power. While approximately one 12-kw wind generator would be needed for each acre, several facts should be considered: (1) Purchased electricity costs are rising rapidly, (2) Bringing electrical powerlines to remote sites is costly, (3) Larger 100-kw wind generators are now under operational test, (4) Removal of water from fine-grained dredged material by any method requires considerable energy, and (5) Wind generators can be transported between sites. A typical 100-acre disposal site might be powered by twelve 100-kw wind generators under the above assumptions, thus dewatering 250,000 cu yd/yr. Spacing the generators at two diameters apart on a line facing the prevailing wind implies an array about 1/2 mile long.

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EXECUTIVE SUMMARY

This report provides a basis for selecting alternative, renewable power sources specifically for operating dredged material processing systems.

A dredged material processing system is designed to: (1) extract sand and gravel for commercial use, (2) remove silt and clay from water to meet quality restrictions on return water, and (3) dewater the residual silt and clay to reduce volume and/or provide a usable foundation for later land use. Currently, processing of dredged material usually consists of holding the hydraulically pumped slurry in a diked containment area and draining off the water after settlement of the suspended material. Subsequent natural drying by evaporation may not significantly reduce the water content of silts and clays for long periods of time (years).

The scope of the assigned task was to provide a screening and selection procedure for the engineer designing a dredged material processing system in order to decide which natural form of energy (or combination), if any, should be chosen to power the system. Power requirements of the mechanical gravel and sand separators would be established when specific equipment is selected for a particular system. Mobile equipment for dredged material processing might be powered from the alternative sources; for example, electric motors could operate on batteries charged by the alternative sources.

The exact power requirements to dewater the fine-grained fractions are unknown because dewatering equipment is presently under development, but alternative power can be provided in several forms. The following were considered in this study:

1. Wind power for driving pumps and electric generators
2. Solar radiation for conversion to thermal and electrical energy
3. Hydraulic power (waves and currents) for driving electric generators.

Some consideration was given to obtaining power from solid waste (such as incineration of trash), but the idea was discarded as not pertinent to the scope of this report. In this report, wind power is presented as

electricity or as shaft horsepower, solar power as heated water or air flow or as electricity, and hydraulic power, possibly, as electricity.

Even though flatplate solar collectors are now commercially available to heat air or water for buildings, they are not well adapted to known or proposed dredged material processing systems. The cost of solar cell electrical power generation, though available, is prohibitively high at present. Likewise, hydraulic power generation by waves, currents, or small hydro-electric plants does not appear to be practical at typical dredging sites.

Of all the alternative power sources studied, wind electric generation seems to be the most practical and versatile to apply at this time. A 12-kw DC wind generator is shown to provide power at Buffalo, New York (best site), for \$0.0243/kw-hr, a price actually less than the typical purchased electricity cost of \$0.0263/kw-hr. Electrical power could be used by the vacuum pumping and electro-osmotic dewatering systems presently under development elsewhere. However, though the unit cost of wind-produced electricity is competitive, the present size limit of 12 kw might imply a large number of wind generators at dredging sites. Such a situation may be deemed impractical at this time.

With an estimate of 0.15 kw-hr to be required to remove 1 gal of water from dredged material by electro-osmosis, the 12-kw wind generator could provide energy to dewater over 2500 cu yd of dredged material in a year at favorable locations. The energy cost for this processing would be \$0.18/cu yd. Vacuum well-point pumping is also being tested by other Dredged Material Research Program investigators using wind-generator power. While approximately one 12-kw wind generator would be needed for each acre, several facts should be considered: (1) purchased electricity costs are rising rapidly, (2) bringing electrical powerlines to remote sites is costly, (3) larger 100-kw wind generators are now under operational test, (4) removal of water from fine-grained dredged material by any method requires considerable energy, and (5) wind generators can be transported between sites. A 100-acre disposal site might be powered by twelve 100-kw wind generators under the above assumptions, thus dewatering 250,000 cu yd/yr. Spacing the generators at two propeller diameters

apart on a line facing the prevailing wind implies an array about one-half mile long.

PREFACE

This report documents work performed by the Civil Engineering Laboratory (CEL), Naval Construction Battalion Center, Port Hueneme, California, as part of the Corps of Engineers Dredged Material Research Program (DMRP). The DMRP is sponsored by the Office, Chief of Engineers (DAEN-CWO-M), and is administered by the Environmental Effects Laboratory (EEL), U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi.

The study was conducted under Task 5C of the DMRP, "Disposal Area Reuse," Work Unit No. 5C08, "Identification of Alternative Power Sources for Dredged Material Disposal Operations," and was performed during the period from June 1975 through June 1976. The report is the result of research to identify, describe, and evaluate presently available or potential systems for converting available resources located in the vicinity of dredging and disposal sites to usable energy for operation of equipment. Both technical and economic feasibility of different power generation systems is considered.

The principal investigator at CEL was C. E. Parker of the Energy Program Office, and the associate investigator was J. B. Ciani. Coauthors of this report were D. Pal and K. F. Vodraska. Others who contributed to this work were F. W. Herrmann, R. E. Kirts, and H. S. Zwibel. The figures were drawn by R. S. Eldridge and D. J. Erwin. The report was edited by V. N. Spafford.

The study was managed by Alfred W. Ford, EEL, for Charles C. Calhoun, Jr., Manager of the Disposal Operations Project, DMRP. The study was under the general supervision of Dr. John Harrison, Chief, EEL.

The directors of WES during the period of investigation and preparation of the report were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. The Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	2.54	centimetres
feet	0.3048	metres
yards	0.9144	metres
miles (US Statute)	1.609344	kilometres
square inches	6.4516	square centimetres
square feet	0.09290304	square metres
acres (US Survey)	4046.856	square metres
cubic feet	0.02831685	cubic metres
cubic yards	0.7645549	cubic metres
gallons (US liquid)	3.785412	cubic decimetres
pounds (mass)	0.4535924	kilograms
tons (short)	907.1847	kilograms
horsepower	745.69999	kilograms per cubic metre
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
British thermal units (international)	1055.056	joules
langleys	41840.0	joules per square metre
pounds (force) per square inch	6894.757	pascals
knots (international)	0.5144444	metres per second
miles per hour	1.609344	kilometres per hour

Multiply	By	To Obtain
feet per second squared	0.3048	metres per second squared
cubic feet per minute	0.0004719474	cubic metres per second
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
BTU per pound (mass)	2326.0	joules/kilogram
BTU per pound (mass) x Fahrenheit degrees	4186.8	joules/kilogram — Kelvin
BTU per hour x feet square x Fahrenheit degrees	5.678263	watts/metre squared - Kelvin
degrees (angle)	0.01745329	radians

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C=(5/9)(F-32). To obtain Kelvin readings, use: K=(5/9)(F-32)+273.15.

IDENTIFICATION OF ALTERNATIVE POWER SOURCES FOR DREDGED MATERIAL PROCESSING OPERATIONS

PART I: INTRODUCTION

Background

1. Dredging of sediments from the bottom of waterways is necessary to permit ship traffic. The dredged material removed is usually disposed by either placement in water outside the waterway or on land. Land disposal often involves a diked containment area where, to permit reuse of the area or the material itself, certain "passive" processing of dredged material traditionally takes place. Dredged material is usually hydraulically pumped to the containment area. The resulting slurry has a very high water content, which presents a difficult problem in draining and drying this material (particularly if the material is fine-grained clay, silt, and organic matter). Therefore, the main effort in future dredged material processing is anticipated to be drying, or dewatering, to reduce volume and stabilize the soil.

2. Historically, when there were few restraints on acquiring marginal land for disposal areas, the dredged material was left to dry rather passively by natural action of sun and wind. Minimal ditching, sluicing, pumping, and other simple assistance to nature were provided. With no great press of time or space, this passive processing continued over several years, typically between dredge fills or "lifts."

3. Now, restrictions imposed by environmental legislation on water disposal and on use of wetlands for disposal sites have caused a trend toward more disposal on land; but, at the same time, population pressures have increased land costs. This conflict has generated research to accelerate the tempo of dredged material processing - indeed, to change it to an active operation. Such active processing requires power. However, costs of energy have been increasing in recent years at very high rates, whereas alternative power system costs are relatively

constant. It is projected that electricity rates will escalate 6% to 7% annually above general inflation; alternative power system costs are projected to increase at general inflation rates.

4. The costs of petroleum products to the military have doubled in the past 2 years; for long-range planning, future increases up to 8% annually above general inflation rates are used. Electricity rates, being fuel dependent, are following similar trends. Thus, the energy costs of dredged material processing present a sizeable problem from the standpoint of fuel cost alone. Therefore, this task was formulated to provide essentially fuel-free power to the processing equipment.

Purpose

5. The objective of the study was to identify and formulate detailed descriptions of presently available or potential systems showing near-future feasibility for converting resources of energy located in the vicinity of dredging disposal sites to usable energy for operation of equipment used in dredged material processing operations. The approach taken was to acquire and organize the information necessary to do site-specific analysis of local source energy systems.

Scope

6. The scope of this study is limited to commercially available alternative power systems or those sufficiently advanced in development to be available in the near future. New untried concepts are not included.

PART II: APPROACH

General

7. The essential approach taken in this work was to acquire and organize information necessary to do site-specific analysis of local source energy systems. The methodologies expected to be analytically employed and a description of the portrayal of results are presented in this report.

8. Three tasks delineated in the Statement of Work for this study are summarized as follows:

- a. Identification and investigation of alternative energy source research and development and specification of work that may be adaptable and beneficial to the objectives of dredged material processing operations.
- b. Identification and description of potential sources of energy available at dredging and dredged material processing sites, including characterization and quantification of the energy resource and quantified descriptions of physical systems used to convert local energy sources. This task was to include investigation of potential wind, solar, and hydraulic power. Consideration was also given to the feasibility of other energy sources.
- c. Evaluation of the potential energy sources and systems by means of illustrative portrayal, data appearing in tabular or graphical form, and technical dissertation including quantitative and qualitative information. The means for detailed site-specific design and evaluation through the use of parametrically presented design, performance, and cost data are provided. Plans and procedures for the adaptation and utilization of energy at dredged material processing operations are recommended.

Study Functions

9. The following study functions were required to accomplish these tasks:

a. Compilation of an information base, including (1) alternative energy research and development reports and results; (2) local source energy data such as winds, insolation, water currents, waste heat, and thermal gradients; (3) energy demands in dredged material processing operations and physical data describing the equipment; (4) physical data describing potential energy systems; and (5) methodologies used to analyze energy sources and systems.

b. Construction of parametric design sizing plots for each system.

c. Construction of parametric energy performance plots for each system.

d. Construction of parametric cost information plots for each system.

e. Preparation of technical dissertation on each system recommending possible plans and procedures for adaptation and utilization.

f. Combining of all study information into a final report.

Methodologies

10. Methodologies were applied in the following areas:

a. Local source energy analysis; i.e., quantities of energy contained at each local source.

b. Energy system sizing.

c. Energy system performance.

d. Cost benefit analysis.

Data Sources

11. Wind and solar energy available in each geographical region was obtained from historical climatological data.

12. Wind-power duration curves were computed using velocity distribution data, and system energy output was computed from the envelope of windmill operation defined within the wind-power duration curve. Spatial correlations of wind energy data were computed by using a method previously derived by the principal investigator. Monthly variations in wind energy were computed from historical data.

13. Solar energy was computed using daily values of insolation for each month taken from weather station records.

14. Quantities of energy available in local water currents, waste heat, and thermal gradients were computed from available data. Energy available in water currents is simply the quantity of kinetic energy contained in a given cross section of flow. Only a certain fraction (0.30 to 0.44), depending on the efficiency of the turbine, can be converted to useful mechanical work. Energy from waste heat or thermal gradients was computed using a Rankine thermodynamic cycle operation between the head source temperature and the surroundings.

Computations

15. Mean values and variations about the mean were computed from local source data. When appropriate, probabilities of occurrence of phenomena related to energy system design, such as amounts of storage, were computed from time-dependent energy data.

16. Sizing depends on the time-dependent energy requirement, time-dependent quantities of available local energy, and efficiencies of energy conversion characteristic of each device. The available local source energy varies from site to site, and there was variation in conversion efficiencies, depending on the approach. Consequently, a parametric method of sizing was necessary.

17. A series of parametric curves were constructed showing the variation of system size with parameters such as energy source intensity, component efficiencies, demand cycle, and local source time-dependent fluctuations. Conventional sizing parameters were used, such as rated power output, collector area, pumping capacity, or storage capacity. Data necessary to size a detailed design appear on these parametric plots. System component efficiencies were taken from the survey of energy research.

18. Energy system performance is presented as a function of local energy source intensity and the time-integrated amount of local energy. For instance, windmill performance is given on two plots. One shows the

windmill system's overall power coefficient as a function of windspeed; the other shows the operational envelope of the windmill on a site-specific annual power duration plot. Area within the operational envelope gives the expected annual energy output. The site-specific power duration curve is computed from windspeed distribution data taken at or near the site. The techniques used to compute these plots are given along with typical example problems so that the method can be applied by the sponsor to any site-specific problem.

19. In the example of computing windmill performance using the power coefficient and then computing a power duration envelope, an optimum load match is assumed to occur between windmill output and load demand. In some applications, optimum load matching is a realistic assumption, but in cases where it does not occur, some technique is required to account for the loss of available energy due to load mismatching. A methodology is given in the study results that can be applied to site-specific load demand and time-dependent local energy source data to arrive at a statistically averaged load factor. Also, a similar method of analysis is given to compute required energy storage capacity, given the probabilities of minimum threshold local energy intensity occurring over specific lengths of time.

20. A similar set of methodologies is given for each type of local energy source. A sizing and performance analysis is made, using selected site data and appropriate energy systems that realistically showed promise of application at the specific sites.

Cost Benefits

21. A complete cost benefit analysis was not made on each alternative power system due to lack of data. The principal problem is that there is little or no basis for comparison inasmuch as there is no dredged material processing of any consequence taking place at present. However, at the time of application of alternative power systems, the following analysis method should be followed.

22. Each energy system should be analyzed for its cost, which should include the capital investment in machinery and its installation, the expected average annual maintenance expenses, and the cost of fuel. Where possible, real cost data should be used; but, when these data are not available, estimates should be made based on cost information obtained on similar devices. Costs of conventional machinery should be computed and used for comparison. Benefits should be computed by applying a present value cost analysis to each system, including a conventional system relying on petroleum fuel for energy. Benefits should then be reflected in a savings in life cycle cost of the local source energy system over the conventional system. The most likely benefit should be a savings in fuel expenses, but it could occur with a savings of capital investment and maintenance and operating expenses. Benefit should be also expressed as a net periodic savings in petroleum fuel. Values of interest rates and expected percentage rise in maintenance, operating, and fuel costs, as well as economic life, should be discussed with the sponsor prior to the analysis, and mutually agreeable values should be used.

23. A savings-to-investment ratio should be computed from the cost-benefit results as a relative measure of the monetary value of the system. In addition, the cost of energy expected to be delivered to the dredged material equipment by the local energy system should be computed from annual expenses and expected annual energy output. Cost data should be parametrically presented in a comprehensive manner for ready use in subsequent site-specific analyses.

Presentation

24. Results are portrayed in tabular, graphical, equation, and pictorial form, depending on the nature of information being transmitted. Data appearing in tabular form include local source energy data, such as appropriate climatological data, physical characteristics of all

existing or conceptual energy systems examined in the study, specific system performance data, specific system cost data, and operating and maintenance data.

25. Graphical results include presentations of available local source energy; time-dependent load and source power curves; parametric design curves, including the appropriate sizing information; and parametric energy performance curves. Mathematical expressions used in the analysis are presented in a comprehensive manner.

26. Pictorial illustrations, such as sketches and drawings, are provided to clarify images of the transmitted information. Sketches of proposed concepts showing their physical size and how they appear on a typical dredged material site are given. Drawings of existing equipment are presented when available.

PART III: POWER SOURCES

Wind Power

Introduction

27. The idea of developing shaft power from the wind is very old. For centuries, windmills of crude aerodynamic design have been in use in Holland, Denmark, and North Germany for grinding wheat. Such wind machines provided high torques at slow rotating speeds but were inherently inefficient because of their low tip-speed-to-windspeed ratio. Small windmills were used to pump water on farms in the United States and in other parts of the world. The Smith-Putnam wind turbine in Vermont, which operated successfully from 1941 to 1945,[1] demonstrated the feasibility of developing large amounts of power from the wind. The two-bladed propeller of the machine was 175 ft in diameter and developed 1,250 kw in a 24-mph wind. This wind machine generated electrical power synchronously. Numerous other wind-power systems in 20- to 100-kw size have been used over the past 30 years.[2-5]

28. The evolution of the internal combustion engine and the growth of public electrical networks forced such windmills to disappear. Because of the diminishing supplies of fossil fuels today, however, interest in wind-power systems is renewed. Several companies market wind machines in 5- to 12-kw capacity. Currently, the National Aeronautics and Space Administration (NASA), under the sponsorship of the Energy Research and Development Agency (ERDA), is developing a 100-kw machine to generate electrical power.[6] ERDA is also funding numerous other wind-energy-related projects at various universities and private companies.[7]

29. Commercial wind generators are available in sizes from 50 to 12,000 watts, with most designed to generate DC power only. Recently, some firms (Aerowatt of France and Elektro G.m.b.h. of Switzerland) have developed wind generators in sizes from 4- to 12-kw to produce 3-phase AC power.

30. The Aerowatt machine is designed to produce 4.1 kw at a windspeed of 16 mph with a propeller of 30.6 ft in diameter. The Elektro machines deliver 5 to 12 kw. The NASA 100-kw wind generator is still under development, and complete data on its performance are not yet available.

31. The old farm-type windmill, because of its high torque characteristics, is well suited to pumping applications. A 6-hp model of such a windmill made by Aeromotor Company is shown in Figure 1. Table 1 lists the necessary operational data on a 5-kw AC wind generator, 6- and 12-kw DC Elektro wind generators, and the 6-hp Aeromotor pumping unit.

32. A typical wind machine unit is designed to last for a period of 30 years. Therefore, when determining the economics of wind-power installations, this equipment life cycle should be used. A 12-kw DC unit installation is shown in Figure 2.

33. The system is more fully described in Appendix A.

Conversion of wind power to energy

34. Feasibility. Wind as a source of energy has many applications, will provide nonpolluting power, and will save fossil fuels for other important operations. Environmentally, the use of wind-powered systems for dredged material processing sites appears to be a promising application. For instance, utilization of wind power for operating dewatering systems may not require any storage of energy. A wind-power installation without storage (depending upon its size, the wind potential, and the remoteness of the site and the construction costs of installing the plant) can produce the power at a cost comparable to that of the existing sources of power such as a diesel engine or, in some circumstances, a public utility. A preliminary survey of the existing wind data indicates that many locations in the continental United States have attractive wind-power potential, thus making the use of wind power for dredged materials processing feasible.

35. Wind power has been used successfully in the past to pump water for drainage and irrigation of land areas in Holland. A typical drainage mill of crude design lifted water to a height of about 3 ft and

on the average pumped about 27,000 gal of water per hour during strong winds. The 19-ft-diameter, 4-bladed propeller of such a machine drained water from 37 to 50 acres of land area. Such mills converted only about 16% of the wind energy into shaft power and operated at tip speeds two to three times the windspeed. Most of the drainage mills used a centrifugal pump capable of handling large water flows under very low heads; however, due to unsteady rotational speeds the pump efficiencies were less than 40%. The inherent low efficiency of the wind-powered centrifugal pumps is due to irregular rotational speeds and low operating heads.

36. The American multibladed windmill has been used for pumping water on farms. Such a wind-power system converts about 30% of the wind's kinetic energy into shaft power; a corresponding figure for a modern propeller system is about 42%. The multibladed rotor, however, offers a good starting torque, a desirable feature for operating reciprocating pumps. The windmill system is a relatively slow turning unit with the rotor-tip-speed-to-windspeed ratio of unity. In comparison, a propeller type rotor turns at tip speed ratios of 4 to 6.

37. Costs. The Aerowatt machine costs $19,000 and is designed to produce 4.1 kw at a windspeed of 16 mph with a propeller 30.6 ft in diameter. In comparison, the Elektro machines for 5 to 12 kw cost between $7,000 and $10,000. Clearly, from the initial-cost point of view the Aerowatt machine is not competitive with the Elektro units. In this study, the Aerowatt and NASA machines will not be included.

38. A 6-hp old farm-type windmill made by Aeromotor Company with a pump and the mounting tower like that shown in Figure 1 sells for about $5,000. The equipment costs, including installation for each unit, are shown in Table 1.

Solar Radiation

Introduction

39. The sun's energy falls upon Earth continuously and gives sustenance to all life. It has been the origin of most energy sources

known to date — wood, coal, natural gas, wind, ocean, etc. The direct conversion of this solar energy output to benefit mankind is currently receiving much research and implementation. With specific attention to dredged material processing operations, solar energy conversion applications present a very formidable challenge.

40. Man has been dependent upon the sun from the beginning of time, and acknowledged its existence in many ways. However, the first most notable attempt at converting this energy was Archimedes' setting fire to an attacking Roman sailing fleet in about 212 B.C.

41. Much development work was accomplished during the Eighteenth, Nineteenth, and Twentieth Centuries on solar energy thermal conversion devices. It was not until the 1930's, however, that the photovoltaic cell proved its ability in directly converting solar energy to electricity.

42. The sun's energy can be converted by one of three processes: (a) solar-chemical, (b) solar-thermal, and (c) solar-electric. Principally, with dredged material processing operations, heat is provided to dry dredged material or electricity is provided to power electrical devices (pump motor). Each of the solar energy conversion processes is briefly discussed in Appendix B.

<u>Conversion of solar radiation to energy</u>

43. The effective application of any solar energy conversion process depends much on the individual components comprising the total system.

44. The solar collector is the heart of the solar energy conversion process — "it's the bucket used to catch the sun's free energy." There are several types of collectors — flat-plate, concentrator, and solar cell — each best suited for converting solar energy to benefit man.

<u>a</u>. The flat-plate solar collector is primarily used for low and medium temperature (less than $200^{o}F$) fluid heating applications. It is the principal design utilized for agricultural product drying, pool water and domestic hot water heating, liquid process heating, and building space

heating and cooling. The main heat-carrying mediums used in the flat-plate collector are air and water (antifreeze, etc.).

b. The concentrator solar collector is chiefly utilized for solar-thermal energy conversion applications necessitating high output temperatures of the heat-carrying medium (e.g., to operate turbines for electrical generation).

c. The solar cell, or photovoltaic cell, directly converts sunlight to electrical current. Chiefly utilized in space vehicle applications in the past, it is currently receiving intensive development for terrestrial applications.

45. Appendix B discusses the basic construction materials and operating efficiencies of the various noted types of "solar collectors," as well as energy storage mediums and ancillary equipment required to make a solar energy conversion system operational.

46. Feasibility. Flat-plate and concentrator solar collectors are currently being utilized in many diversified cost-effective applications. The photovoltaic cell, however, is still much in the development stage and limited to remote-access applications where conventional power is difficult to obtain.

47. Applications. Electrical generation and drying are those applications of the sun's energy that are economically appropriate to meet the energy demands for dredged material dewatering.

48. Converting the sun's energy into electrical power is an important concern because of the dependence upon electrical devices in the United States. The solar-thermal-electric energy conversion process (solar concentrators, heat engine, and electrical generator) results in low overall efficiency and presents control and maintenance problems. The direct solar-electric process eliminates intermediate conversion equipment and requires minimum maintenance. The solar-electric process is more practical than the solar-thermal-electric process because of the limited and sparsely located electrical equipment at dredged material processing operation sites. Yet both solar energy conversion processes are still far from being cost-effective, when current or projected

availability and cost of conventional fossil fuels are considered, as well as the costs for material, labor, and maintenance of energy conversion process equipment. However, the process for future electrical generation, at selected or remote site locations, definitely points to that of direct photovoltaic conversion.

49. Solar energy naturally helps dewater dredged material spread on the ground and exposed to the sun's heat. This natural method has two distinct disadvantages: (a) an insufficient amount of sun energy may be available to evaporate water as quickly as desired; and (b) the lack of control of the surrounding atmosphere to enhance evaporation and prevent the addition of unwanted moisture (such as rainwater).

50. Costs. It is difficult to accurately predict the cost of undeveloped systems; however, some rough estimates can be made.

51. Direct production of electricity by photovoltaics today costs between $5 and $20 per peak watt. At such costs the payback period is too large to consider. However, the Energy Research and Development Administration (ERDA) optimistically predicts that in 10 years the cost will be reduced to $0.50 per peak watt. Under these conditions, a cell with 1-watt peak capacity operating for 1 day could produce about 5 watt-hours of energy. A simple payback period based on commercial electricity at $0.05 per kilowatt hour is 7 years. In other words, after 7 years, the electric power from the photovoltaic cell would be free. The life expectancy for a solar cell is 15 to 20 years.

52. Mechanical power can be produced by using solar energy as a source of heat, but such solar-powered systems are not commercially available today, although they have been used over the past three centuries. Again, it is difficult to predict the total cost of a solar-powered engine; however, a minimum cost of the solar collection required can be obtained as follows: under favorable conditions the incident solar energy is about 0.1 hp/sq ft of surface area (oriented perpendicular to the direct solar radiation). If an overall system efficiency of

10% is assumed, then 100 sq ft of collector surface area would be required to power a 1-hp engine. At present prices of $10 to $20 per square foot of collector area, the collector cost would be between $1000 and $2000.

Hydraulic Power

Introduction

53. Among the alternative power devices that may be able to provide power for the equipment at dredged material processing areas are those using hydraulic energy. For this study, hydraulic power systems include those that convert the energy in tides, ocean thermal gradients, salinity differences, waves, or currents to usable power.

Discussion of systems considered

54. Tides. In the past, tides have received more attention than any other as potential sources of hydraulic power because these sources are predictable — but they are also highly site dependent. This site dependence has limited serious consideration of large tidal power plants primarily to France, Russia, and the United States, where there are sites with very high tide ranges lying near large natural basins.[8-10] No matter what size the tidal power plant is, large water storage basins are required.

55. Tidal power systems do not appear to hold promise as potential sources of power for dredged material processing. This is true because: (a) although tidal power may be cost effective on a large scale, it is probably not economical on the scale that would be required for dredged material processing; (b) the efficient use of tidal power on any scale depends to a large extent on the range of the tides at the dredge sites, and the tide ranges at the sites of interest in this study are not over 10 ft; and (c) tidewater holding basins that are required as part of tidal power systems are not generally available and could be used more efficiently as dredged material processing areas than as adjuncts to a power system for dredged material processing. Therefore, tidal power systems will not be considered further in this study.

56. Ocean thermal gradient. Presently, interest in renewable energy sources is focused on ocean thermal gradient power systems that use cold water at depth in the ocean and the warmer water near the surface in heat exchangers to produce power. The thermal gradients in the ocean are quite constant and remain so throughout the year at any location in the deep ocean. The power (from the sun) dissipated in maintaining the temperatures in the ocean is equal to about 40 billion Mw.[11] But at a typical location in the tropics, this vast amount of power manifests itself as only a 27°F difference in temperature between the warm water at the surface and that 650 feet below.[12] The efficiency of a heat exchanger operating with this meager temperature difference is very low (probably less than 4%).

57. Nearshore thermal gradients are not nearly as constant as those in the deep ocean, and the temperature differences are much smaller. These characteristics make thermal gradient energy conversion unsuitable for nearshore waters. Therefore, this source of power will not be considered further as a power source for dredged material processing.

58. Salinity. One potential source of hydraulic power that is present near many dredge sites is that of salinity differences. Such differences exist where freshwater meets seawater (e.g., at the mouth of a river at the ocean or in an embayment). It was theoretically estimated by Norman[13] that a United States total of almost 120,000 Mw of salinity power exists from runoff into the oceans and the Gulf of Mexico. The fact that this type of energy exists is evidenced by the osmotic pressure that builds up at a semipermeable membrane separating fresh and saline water and drives the freshwater to the other side.

59. Some laboratory models of devices to tap energy from salinity differences have been devised,[8-10,14] but this energy source has not as yet been adequately researched.[15] The development of an operational salinity power system is not expected in the foreseeable future, so this source of power for dredged material processing will not be considered further in this report.

60. Waves. The most clearly evident source of hydraulic energy is that of the waves that come to shore and expend their energy in breaking. Many devices have been conceived for conversion of wave energy to usable power. Available wave energy depends on the wave height (the vertical distance between the trough and crest of the wave) and period (the time between successive waves). High waves of long period have more energy than low waves of short period. Ocean waves vary widely, and the characteristics of these waves differ with location, season, and year.

61. Four types of wave power systems have been conceived: (a) wave-induced surge, (b) orbital water particle motion, (c) vertical motion of the water surface, and (d) pressure changes under water. However, none of these wave power systems are much beyond the conceptual stage for land-based applications.

62. The combination of the wave characteristics at dredged material processing sites may make energy from waves a viable alternative and one of the wave power systems above may make this extraction possible. Therefore, the equipment and analysis methodologies for wave power systems are described in Appendix C.

63. Current. Another potential source of hydraulic power is water current. These currents include the major ocean currents, the currents in inland watercourses, the flow of dredged material in dredging operations, and the tidal currents in coastal waters.

64. The feasibility of extracting sizeable amounts of power from the Florida Current portion of the Gulf Stream System, the most rapid ocean current near the U.S. coast, was investigated in 1974. It was found that, although the kinetic energy in the Florida Current off Miami has the potential of producing 25,000 Mw, it might not be possible to extract more than 4% of this power.[16] The highest speed portion of the Florida Current is several miles offshore* and limits the application of this potential source of hydraulic power for small shore-based activities, such as confined dredged material processing.

* True of most major ocean currents.

65. Inland watercourse currents, on the other hand, may exist beside, or very near, dredging sites. The direct use of these currents without damming a stream or requiring a significant difference in elevation along the stream is possible with turbines installed directly in the flow of the watercourse or with waterwheels. Power turbines are presently under development but are not yet available off the shelf. Waterwheels, used for centuries, are very inefficient compared to turbines.

66. Currents in inland watercourses which may be dammed and have significant elevation differences along the stream can also be used to generate power. Small dams are used to store and elevate the water and discharge it through pipes to small hydraulic turbines that are available off the shelf. These turbines require an elevation head of at least 6 ft and produce power up to 10 kw.

67. Connecting such a turbine to the pipe carrying the discharge from hydraulic dredging operations could be another source of hydraulic power. The feasibility of using a solids-laden effluent to drive a freshwater turbine has not been demonstrated.

68. Tidal currents in coastal waters (like inlets to bays or upstream of river mouths) change direction and distribution with time. This difference in flow characteristics from those of inland watercourses, which normally have unidirectional flow, requires adjustments to the power plant design to give effective energy recovery.[17] Such adjustments are possible.

69. Major ocean currents as a power source for dredged material processing are not feasible.

70. Direct use of unidirectional currents in inland watercourses and tidal currents in coastal waters without dams may have application to dredged material processing operations. Such current power systems and the analysis methodologies for these are described in Appendix C.

71. Use of small off-the-shelf turbines for power generation from currents in inland watercourses with significant elevation differences along the watercourse and which may be dammed may be possible but is

site dependent. Adequate information is readily available on these turbines from manufacturers, like James Leffel Company in Springfield, Ohio; this equipment will not be discussed further in this report.

72. Feasibility of using these small turbines to extract power from the discharged material from dredging operations is questionable.

Conversion of hydraulic power to energy

73. Feasibility. Waves and currents are more reasonable alternative power sources for dredged material processing operations than other hydraulic sources. Tides, ocean thermal gradients, and salinity differences are considered much less feasible alternatives at present. Consequently, only wave and current power systems are addressed further.

74. Applications. Presently, wave or current power systems are not used extensively, and equipment is not available off the shelf except for small hydraulic turbines which generate small amounts of power (under 10 kw) from currents in dammed streams. These systems are usually found in rural areas, and the power they produce is used for domestic applications.

75. Costs. Cost information for hydraulic power systems of the wave and current types is minimal since these systems are primarily still in the early stages of development.

76. *Wave power systems* cannot compete with existing power systems at today's fuel prices.[18] Based on the rough calculations these authors made without even including costs of moorings, accumulators, power generators, and turbines, a wave power system would cost \$750/kw of installed capacity. These calculations were made for waves of 5-ft height and 4-second period.[18]

77. *Current power systems* that require no head are under development, and an estimate of their cost was made by Somers and Shoupp.[19] These authors, basing their estimates on immersed Kaplan turbogenerator units operating in the Florida current, calculated minimum costs of \$100/kw for 50,000-kw units and about \$200/kw for 5,000-kw units.[19] Scaling laws would probably raise the cost of a 500-kw unit of this type to over \$300/kw.

78. Current power systems for watercourses with elevation differences along a river which may be dammed are available off the shelf. The costs of these systems are a function of the available head and quantity of flow in the watercourse. Typical costs for a head of 10 feet and flows as given are:

Power (kw)	Flow (ft^3/min)	Cost per kw ($)
1	155	6300
3	370	2400
5	590	1550

Do-it-yourself units of this type can be made for elevation heads as low as 1.5 ft if reservoir land is available to contain the water. Such units are likely to be less efficient and more costly per kilowatt than manufactured units.[20]

PART IV: REGIONAL ASSESSMENT OF POWER SOURCES

Wind Power

Potential for nine sites

79. The wind-power potential of a given site is determined by use of the power duration curves in Figures 3 through 11 to compute the output of a wind machine of known performance data. For demonstration of the detailed computations, the output of the 5-kw AC Elektro unit was computed for the Buffalo site and is given in Table 2. Thus, by use of the wind data for each site and Equation A4, the output of the 5-kw unit was computed on a monthly and annual basis for all nine sites. The tabulation of results includes the available energy in the wind, the wind machine output, and its specific power output (SPO) by the month and year for the site. The results also include the average power coefficient for the machine at the site. A mean monthly value was recorded with the months of the year in which excess or deficiency of energy occurs. For completeness, the details of the predicted monthly and annual data on the performance of the 5-kw unit for the remaining eight sites are listed in Appendix D.

80. For comparison, the total annual outputs of the other Elektro wind generators (the 6- and 12-kw DC power plants) were also computed for all nine sites and are shown in Table 3. There is a very small difference between the outputs of the 6-kw DC and the 5-kw AC units. The energy output of the 12-kw unit, however, is generally about 75% higher than the other two. The specific power output of the 5-kw AC unit is invariably higher than that of the 6-kw DC unit, which, in turn, is higher than that of the 12-kw DC unit. The data show that the 5-kw AC unit delivers its full rated output for a longer period than the other two units, thus showing a better match between unit and site.

Cost information

81. The economics of wind power were determined for each site by dividing the equipment and installation costs of each power plant by its total output for a period of 30 years. Table 4 shows distribution of initial costs of the plants on a kilowatt-hour basis for the machine. It should be noted that at present the wind generators available commercially are not mass-produced and, thus, the cost of fabricating each unit is considerably higher than if it were mass-produced. Hence, to make a reasonable estimate of the initial costs per kilowatt-hour output of a wind-power installation, the interest on the initial capital required for the installation is not taken into account. In other words, it is assumed that the total cost, including the interest on the capital of a mass-produced unit, will be equal to the present selling price of the unit. It is clear from the data given in Table 4 that the equipment and other initial costs of delivering energy by the 5- or 6-kw units at Buffalo is about $0.0320/kw-hr, whereas, for the same units installed in the vicinity of Savannah, it is about $0.0845/kw-hr. Costs for the 12-kw unit, however, at these locations are $0.0243 and $0.0657/kw-hr, respectively. The ascending order of initial costs per kilowatt-hour of energy for the various sites is Buffalo, Galveston, Seattle, Norfolk, Detroit, Mobile, Philadelphia, Portland, and Savannah. It can be seen from the data that the distribution of initial costs for each kilowatt-hour for the 12-kw wind generator is generally about 22% lower than for the 5- or 6-kw machines. The costs for the 5-kw AC and 6-kw DC units are very close at all locations except at Portland, where the 5-kw machine is about 11% higher than the 6-kw unit.

Solar Radiation

82. The amount of sun energy available at the earth's surface is chiefly dependent upon: (1) geographical location, (2) altitude, (3) climatic conditions, (4) time of day and year, and (5) inclination and

orientation of the solar energy receiving surface. Recorded solar energy data, received on horizontal surfaces at selected site locations, are displayed in Table 5 and in Figure 12 for comparison only. If the collector surface is tilted facing south, the inclination angle greatly affects the amount of solar energy it receives throughout the year. This relationship is detailed in Appendix D, as well as other particulars pertinent to determining the availability of the amount of solar energy under given conditions.

Hydraulic Power

Potential for nine regions

83. Wave power. The characteristics of ocean waves (height and period) vary widely on the coasts of the United States. Most of the waves off the West coast of the United States range in height from 3 to 10 ft with periods from 5 to 11 sec; on the East coast, 1 to 8 ft, 5 to 9 sec; and on the Gulf coast, 1 to 5 ft, 1 to 5 sec (abstracted from data compiled in Reference 21). On both the East and West coasts higher waves of longer periods are found in the winter, but on the Gulf coast the wave heights and periods do not vary much except during hurricanes. The West coast appears more promising from the standpoint of the amount of wave power available; the East coast, less so; and the Gulf coast, least. However, Gulf coast waves would provide a more constant source of power, and their regularity may be an overriding consideration. Therefore, the wave characteristics at dredged material processing sites on any U.S. coast may be such that waves represent a viable energy source.

84. However, waves are found at only two of the nine sites considered: Galveston with waves averaging between 1 and 5 ft and Toledo with waves averaging 1 ft with occasional maximums of 8 ft. These waves are not consistently high enough to warrant further consideration of wave power as an energy option.

85. Current power. Theoretically, any unidirectional current may be used for the direct (i.e., without damming the watercourse) generation of power, but the economics of generating power (the capital cost of the equipment versus the cost benefits of the power produced) from weak currents make this generation infeasible. Only one of the nine sites has a purely unidirectional current: Cayuga Island in the Buffalo District where the average current is only 1.5 knots. Power generation at this site with this current would require a very large turbine with a volume of over 30,000 ft^3.

86. Although tidal currents, as well as unidirectional currents, can be used to directly generate power, a lower limit (2.1 knots) to the tidal current speed required to generate power exists. This limit is available in one direction (ebb or flood) at five of the nine sites considered, but at only one site (Portland District-Clatsop Spit) in both directions.

Relative regional costs

87. Four types of wave power systems have been conceived, but none of these has gone much beyond the conceptual stage of development for land-based applications. Preliminary estimates of the cost of wave power systems indicate that these systems cannot compete with existing power systems at today's fuel prices. Use of waves as an alternative source of power for dredged material processing is not feasible for the nine sites considered here.

88. Current power systems for use in either unidirectional or tidal currents for watercourses that may not be dammed were considered. It was found that for unidirectional currents the vertical axis turbine was preferred; and for tidal currents, the Savonius rotor. Equipment components for these have been developed, but total systems for power production have not yet been assembled and tested. The power available from these is a function of the area of the system projected in the direction of current flow and the cube of the current speed. For example, a typical vertical axis turbine 60 ft in diameter with an overall efficiency of 44% operating in a 2-knot unidirectional current would produce 50 kw.

89. Current power systems can be obtained off the shelf for dammed watercourses with an elevation head of at least 6 ft. The power generated with these off-the-shelf systems depends on the head and the flow in the watercourse but is limited to 5 kw when the elevation head is less than 10 ft.

90. The cost of current power systems for use in watercourses that may not be dammed is estimated at $300/kw, assuming that a 500-kw system is used (this is the smallest current power system of this type that has been considered). The cost of a typical current power system (hydraulic turbine) for use in a dammed watercourse with a head of 10 ft is $1,550/kw for a 5-kw system.

PART V: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

General

91. Wind machine. Wind machines are commercially available now to provide electrical or mechanical power. Wind-generated electricity is shown to be comparable in cost to purchased electricity at certain dredging sites. However, even though wind power concepts are cost beneficial, they might prove to be technically unattractive because of the relatively low outputs available from a single machine. Matching of wind-derived energy to processing systems requires additional effort.

92. Solar radiation. Commercial thermal solar collectors are not well adapted to proposed processing systems. Solar cell electrical devices are not cost competitive with conventional electricity sources at present.

93. Hydraulic power. Hydraulic power extraction from river currents, though possibly applicable, is not readily available. Wave power is limited in application and not commercially available at this time. Mini-hydroelectric plants on nearby streams may be applicable at certain sites.

Wind power

94. The following conclusions were reached:

a. Utilization of wind power to operate the dewatering systems at dredged material processing sites seems to be very promising at Buffalo and Galveston - each with an annual available energy density of 166 and 147 kw-hr/sq ft of the disk area, respectively. The sites in the vicinity of Norfolk, Detroit, Mobile, Philadelphia, and Seattle show marginal potential with yearly available energy density varying from 84.8 to 115 kw-hr/sq ft of the disk area. Finally, the sites near Savannah and Portland, each with an energy density of 57 and 67.6 kw-hr/sq ft/annum, show relatively poor promise.

b. Many practical constraints exist, however, which can influence the application of wind power at dredged material sites, such as the necessity for special foundation designs and availability of suitable pumping equipment. Additional

research is required to determine the various constraints and their effect on the utilization of wind power at these sites.

c. Commercial wind machines with or without a generator with 5- to 12-kw size are on the market and can deliver either AC or DC power or drive a water pump. In particular, 6-kw DC, 5-kw 3-phase AC, and 12-kw DC units are readily available from Elektro company in Switzerland while a 6-hp wind-powered pumping unit is marketed by Aeromotor Company in the United States. These systems, with some modifications, can be adapted to the dewatering operations.

d. With commercial wind generators the cost (excluding the interest on the capital) of energy per kilowatt-hour delivered at Buffalo by the 6-kw DC, 5-kw AC, and 12-kw DC units is estimated at $0.0317, $0.0323, and $0.0243, respectively. The cost per kilowatt-hour for the same three units at Savannah is $0.0847, $0.0843, and $0.0657, respectively. The cost of wind-generated power at the remainder of seven sites varies between that of Buffalo and Savannah (Table 4).

e. A procedure for computing wind energy potential using existing long-term data for a site is presented, and it is shown that the windspeed and the corresponding power duration curves are powerful tools in estimating the wind-power potential of a site. It is suggested that special attention be given to the time of year in wind-power analysis because there are substantial variations in wind velocities from month to month. Next, the concept of the specific power output, a commonly used parameter for evaluating the performance of a given wind machine installation, is introduced.

f. A correlation scheme, based on the statistical theory of turbulence, enables a wind energy prospector to readily and economically estimate the wind-power potential of a site without long-term wind data simply by making short-term measurements on the site and correlating them with the long-term data from the neighboring weather stations. The correlation scheme yields good results in cases where wind data follow the normal distribution. However, more work is required to extend the method to incorporate the effects of thermally induced turbulence and local terrain roughness. This will be published separately.

g. The method of mechanically mixing the wind generator output with the existing utility grid to operate a water pump at constant speed improves its efficiency and delivers continuous stable power.

Solar radiation

95. Dredged material processing operations present a formidable challenge for solar energy conversion applications. Basic considerations are as follows:

- a. Water elimination from dredged material is of chief concern.
- b. Working environment, usually close to coastal waters, usually indicates an overcast sky and water-salt-corrosion/wind-spray conditions.
- c. Ground surface may be both muddy and dirty, as well as unsettled.
- d. Electrical power requirements are high for driving pumps, which would necessitate large solar collector receiving surface areas.
- e. Available space for solar collector array structures is limited.
- f. Locations of operations tend not to be fixed in a static position.

Hydraulic power

96. In the evaluation of hydraulic power sources as alternatives to conventional power for dredged material processing operations, currents or waves were found to be better alternative sources of power than tides, ocean thermal gradients, or salinity differences.

97. Current power systems for watercourses that may not be dammed have not been developed. However, current power systems for watercourses that may be dammed are available off the shelf and may be used where there is adequate reservoir space. Machines deriving their motive power from the end of pipelines have not been developed.

Recommendations

General

98. It is recommended that a wind generator be installed at Buffalo or Galveston matched to a suitable dredged material processing system to demonstrate the utility of alternative power systems.

Wind power

99. Although wind generators with 5- to 12-kw capacity are

commercially available, the methods and hardware to utilize their variable outputs to match the characteristics of dewatering equipment at dredging sites have to be developed for efficient utilization of wind power. Further work, therefore, is recommended, as follows:

- a. Investigate impact of factors involved in practical utilization of wind power.
- b. Explore further the use of an automatic load switching device for matching loads to the generator's output and its use as a power mixing device.

Solar radiation

100. With regard to the findings and special emphasis on simplicity, reliability, and cost-effectiveness, the following recommendations are presented.

- a. Attempts at electrical generation, via either the solar-thermal-electric or direct photovoltaic conversion, should be considered "experimental" - with all associated risks because of: (1) the low energy-conversion efficiency of the system, (2) the expensive capital equipment, and (3) the system hardware maintenance/control upkeep.
- b. Thermal storage of solar energy should not be considered because of: (1) space limitations, (2) weight capacity consideration, and (3) movement of operations.

Hydraulic power

101. Current power systems for dammed watercourses are recommended where elevation head of over 6 ft along the watercourse can be obtained and where the power required is less than 5 kw.

102. The following are not recommended:

- a. Tidal, ocean thermal gradient, and salinity hydraulic power systems, because they are not feasible for dredged material processing operations.
- b. Wave power systems, because land-bound applications are still under development and none of the nine sites have suitable wave conditions.
- c. Current power systems for undammed watercourses, because these are still under development.

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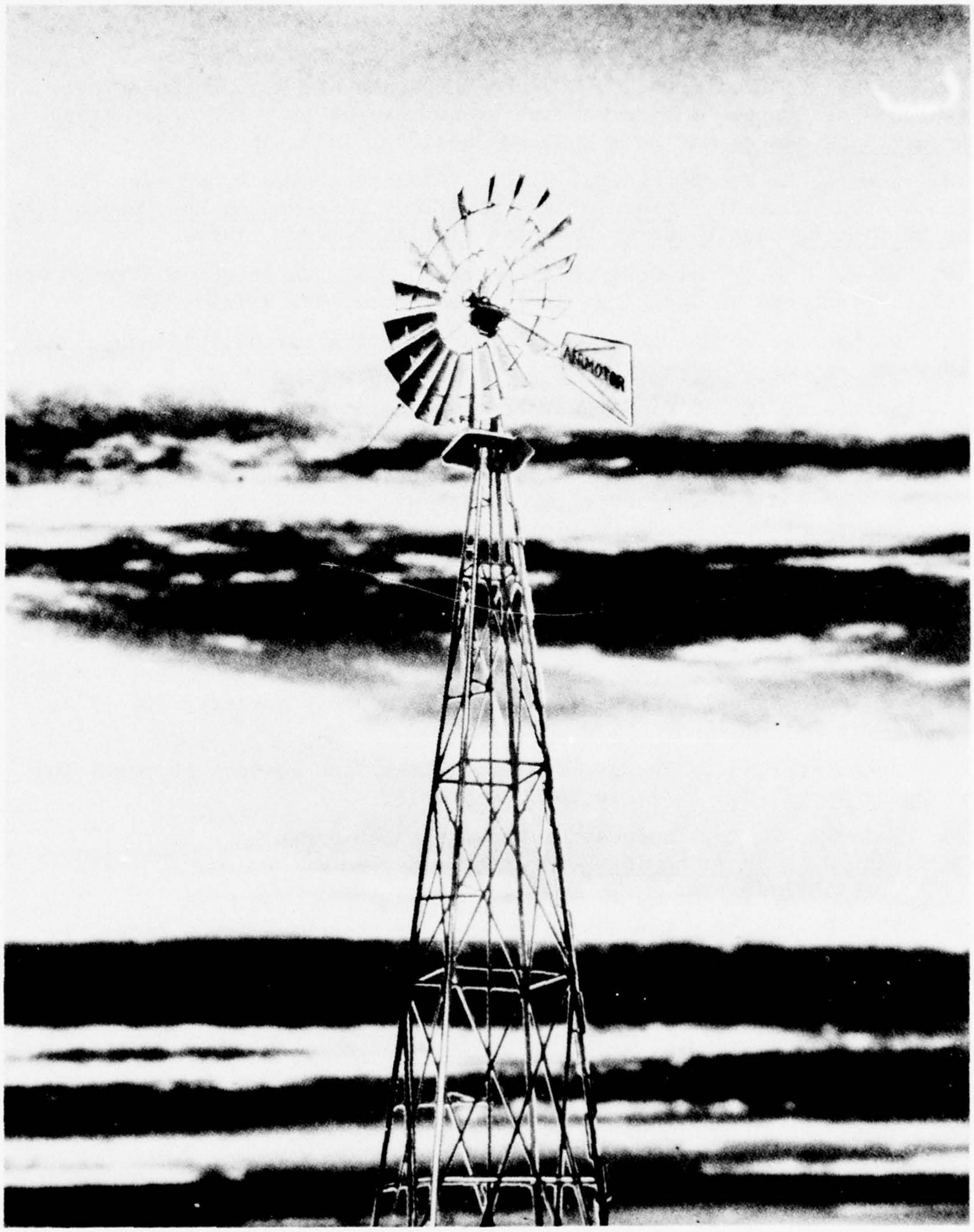

Figure 1. Aeromotor 6-hp, wind-driven water-pumping unit with a rotor diameter of 16 feet

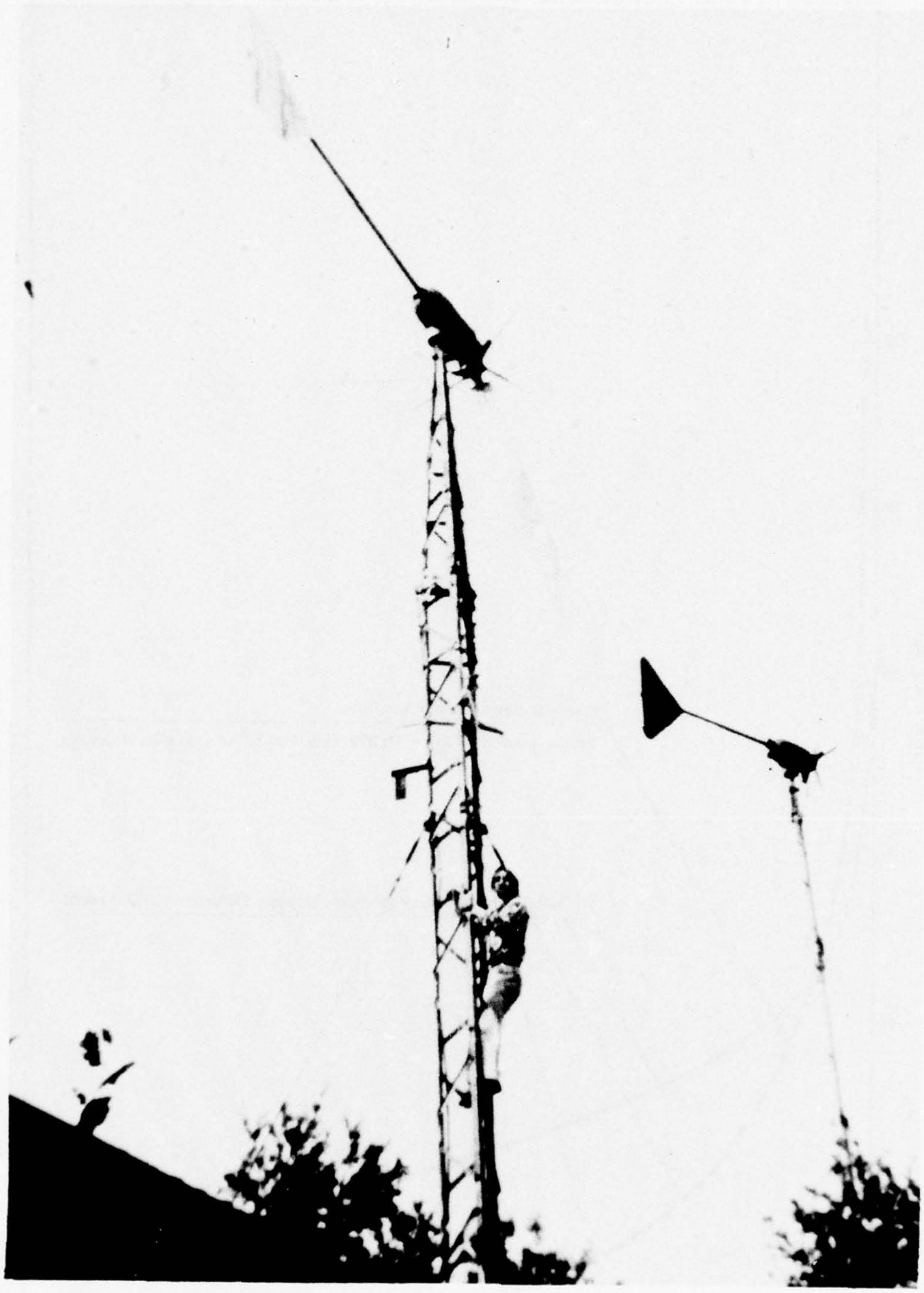

Figure 2. Elektro 12-kw DC wind generator installation near Wintertzur, Switzerland. The wind machine has a propeller 21 feet 6 inches in diameter

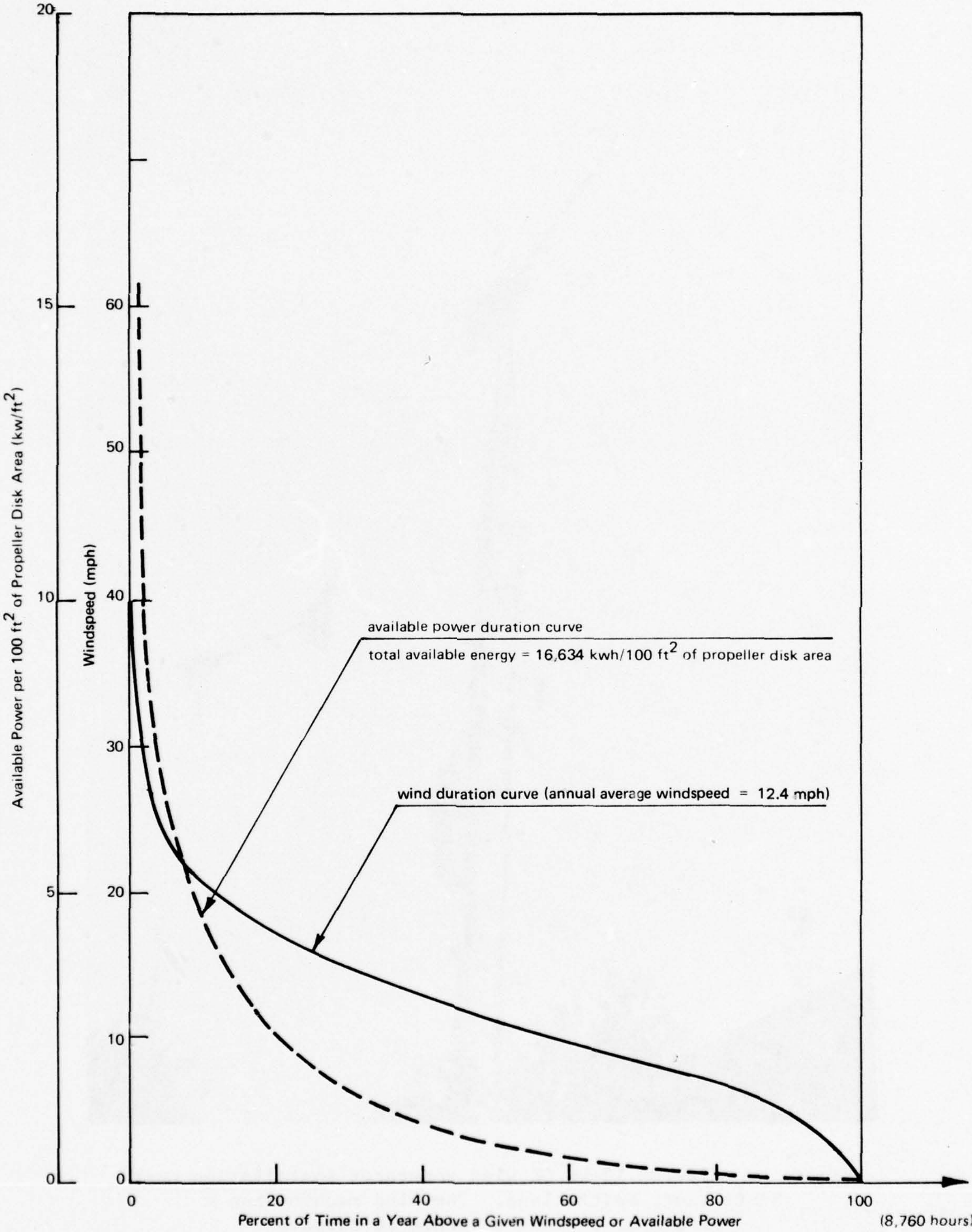

Figure 3. Windspeed and power duration curves for a site near Buffalo

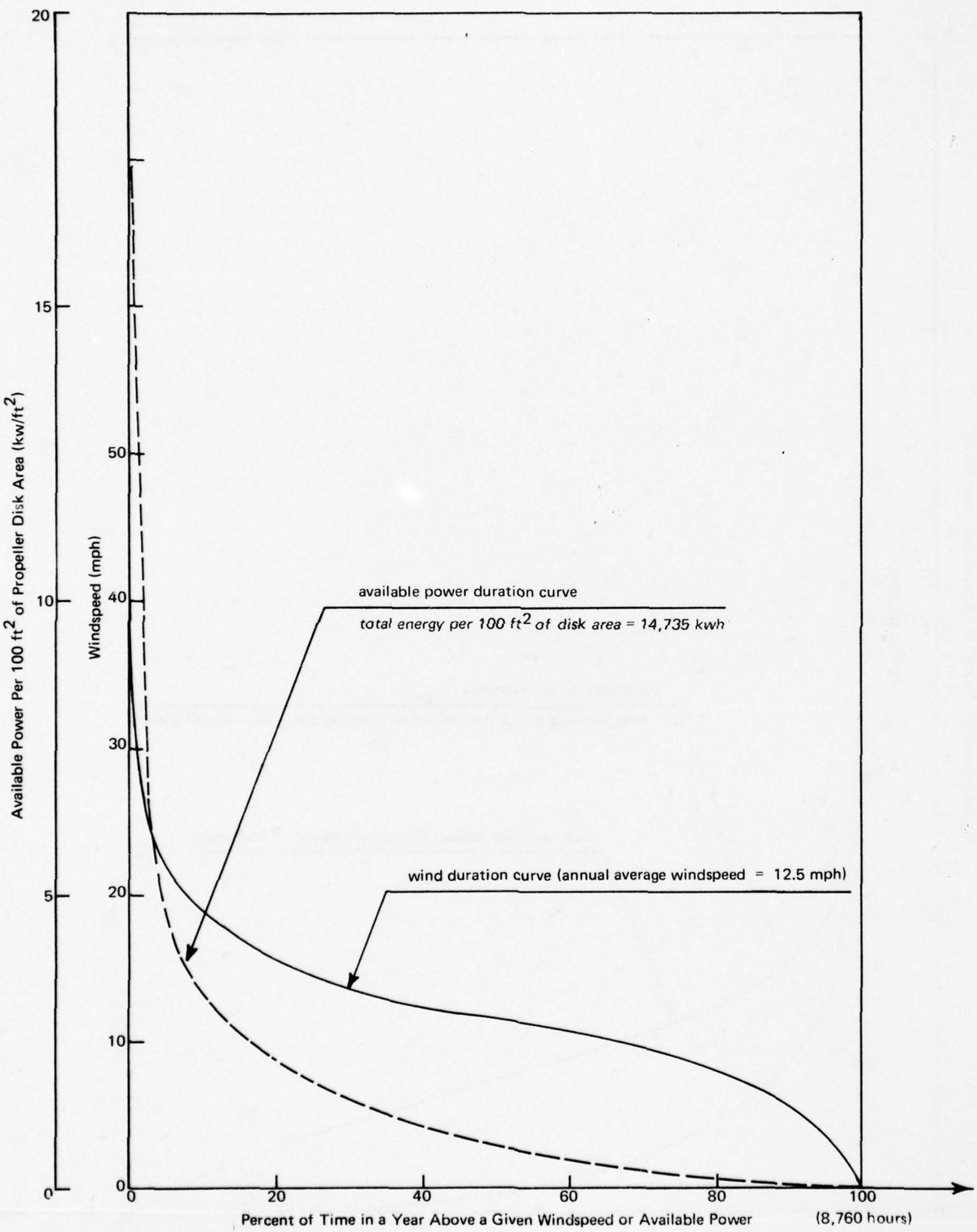

Figure 4. Windspeed and power duration curves for a site near Galveston

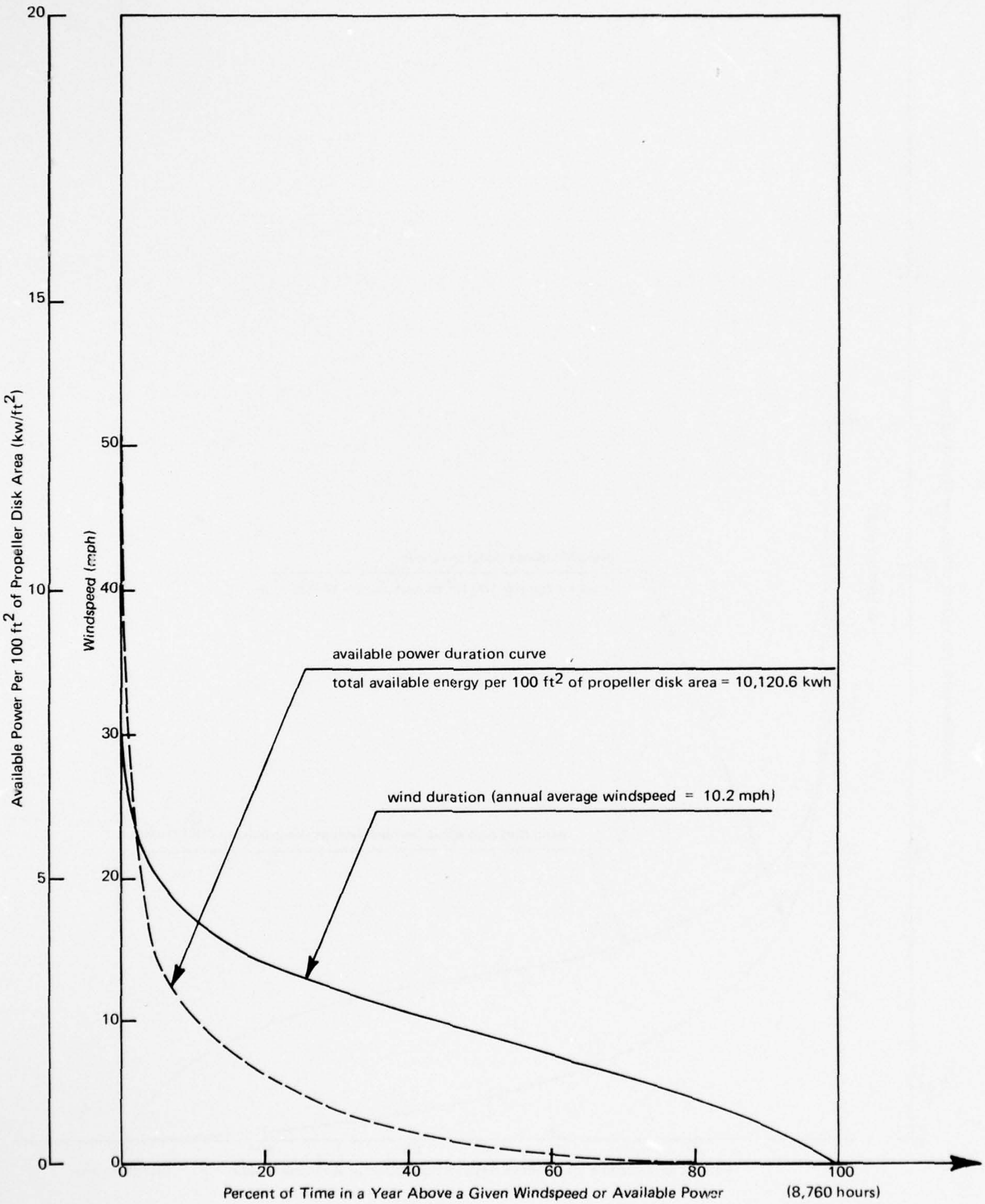

Figure 5. Windspeed and power duration curves for a site near Norfolk

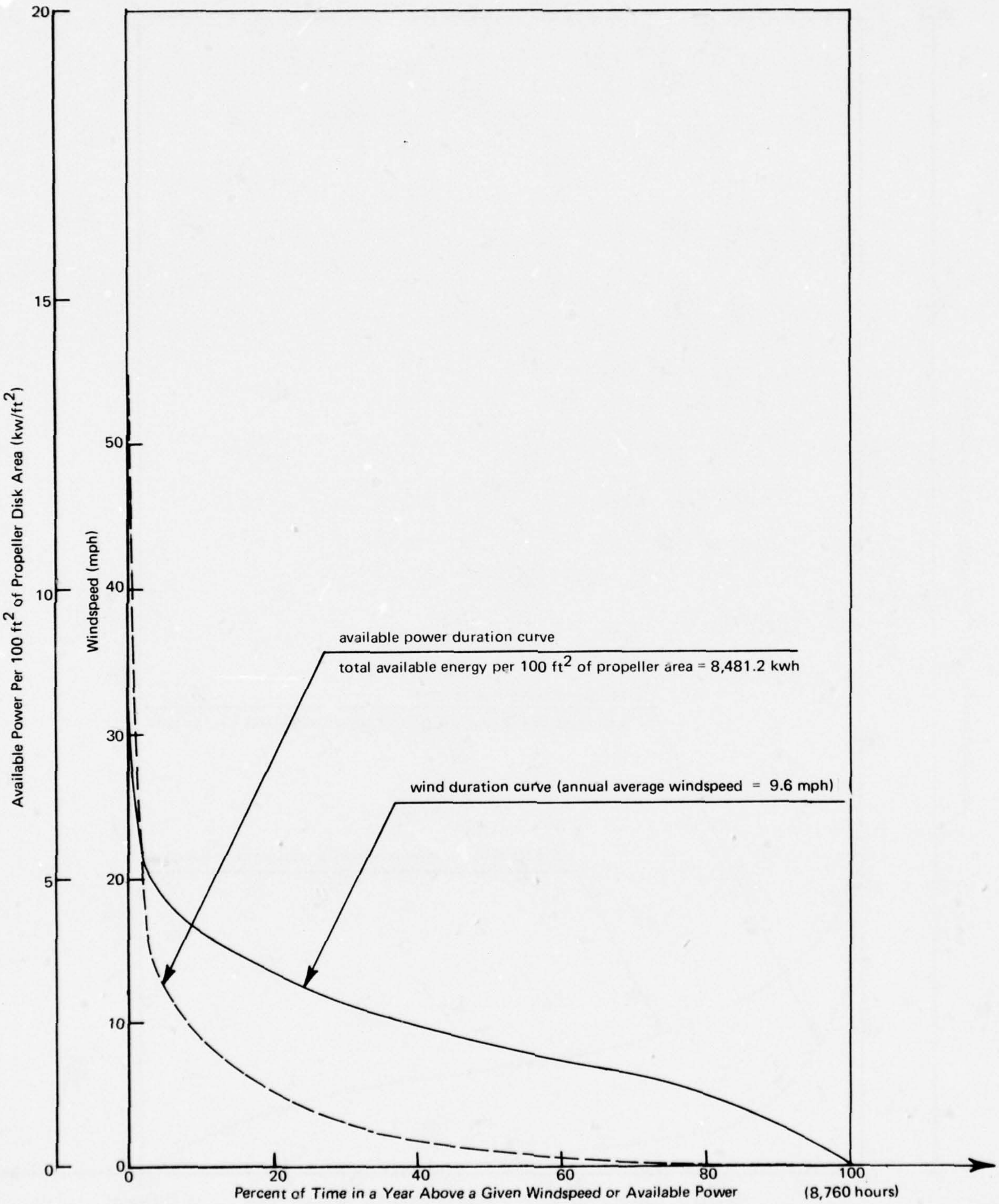

Figure 6. Windspeed and power duration curves for a site near Philadelphia

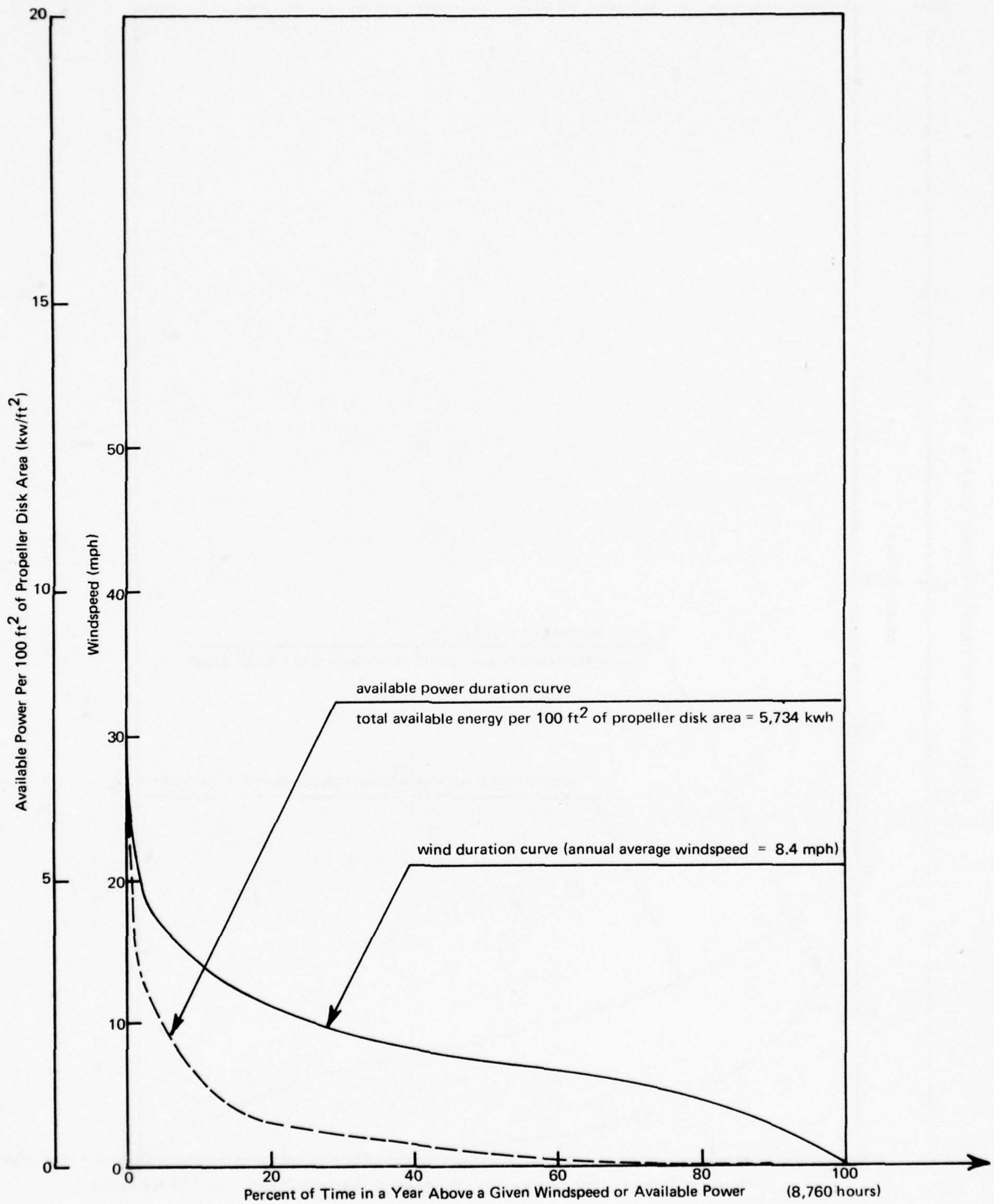

Figure 7. Windspeed and power duration curves for a site near Savannah

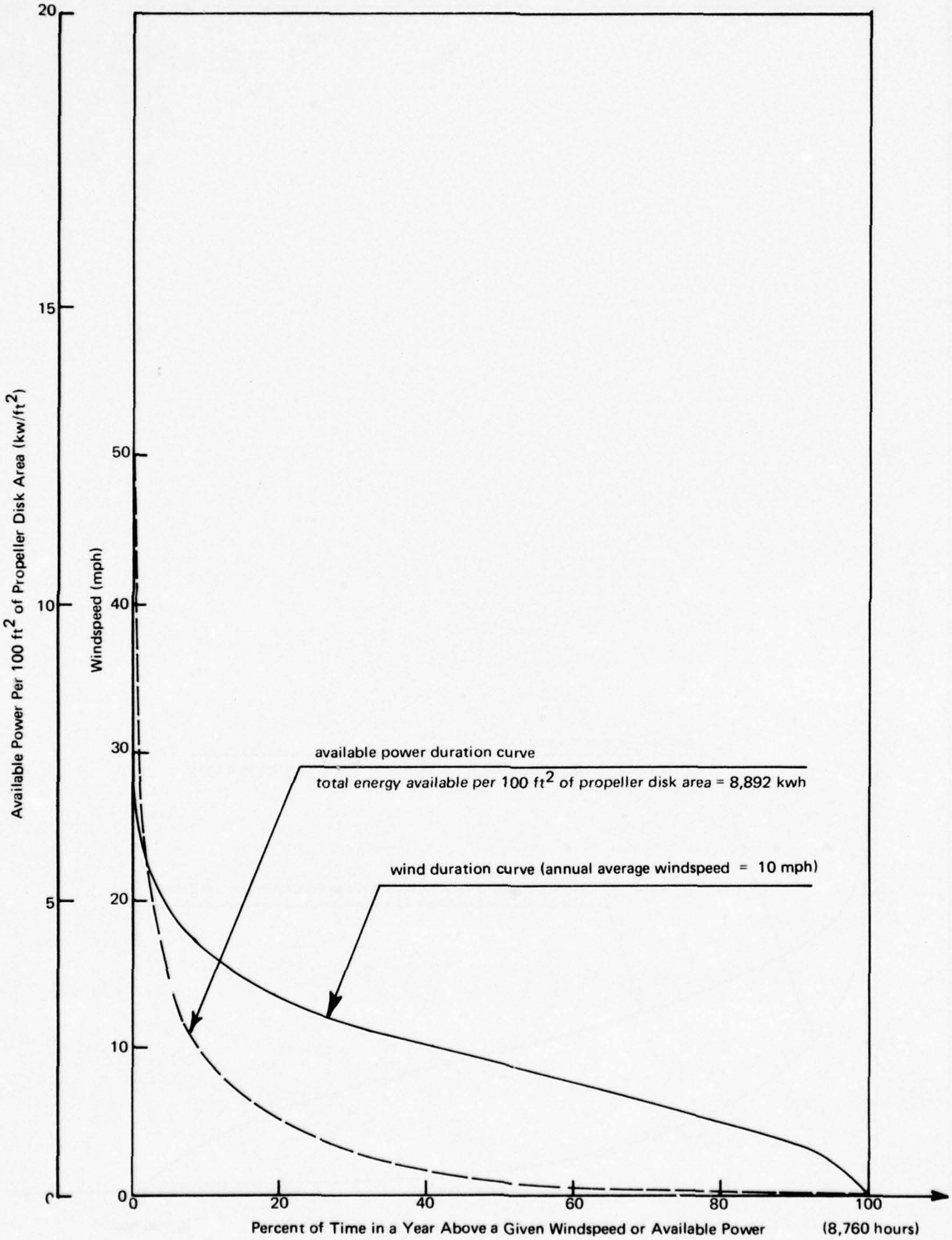

Figure 8. Windspeed and power duration curves for a site near Mobile

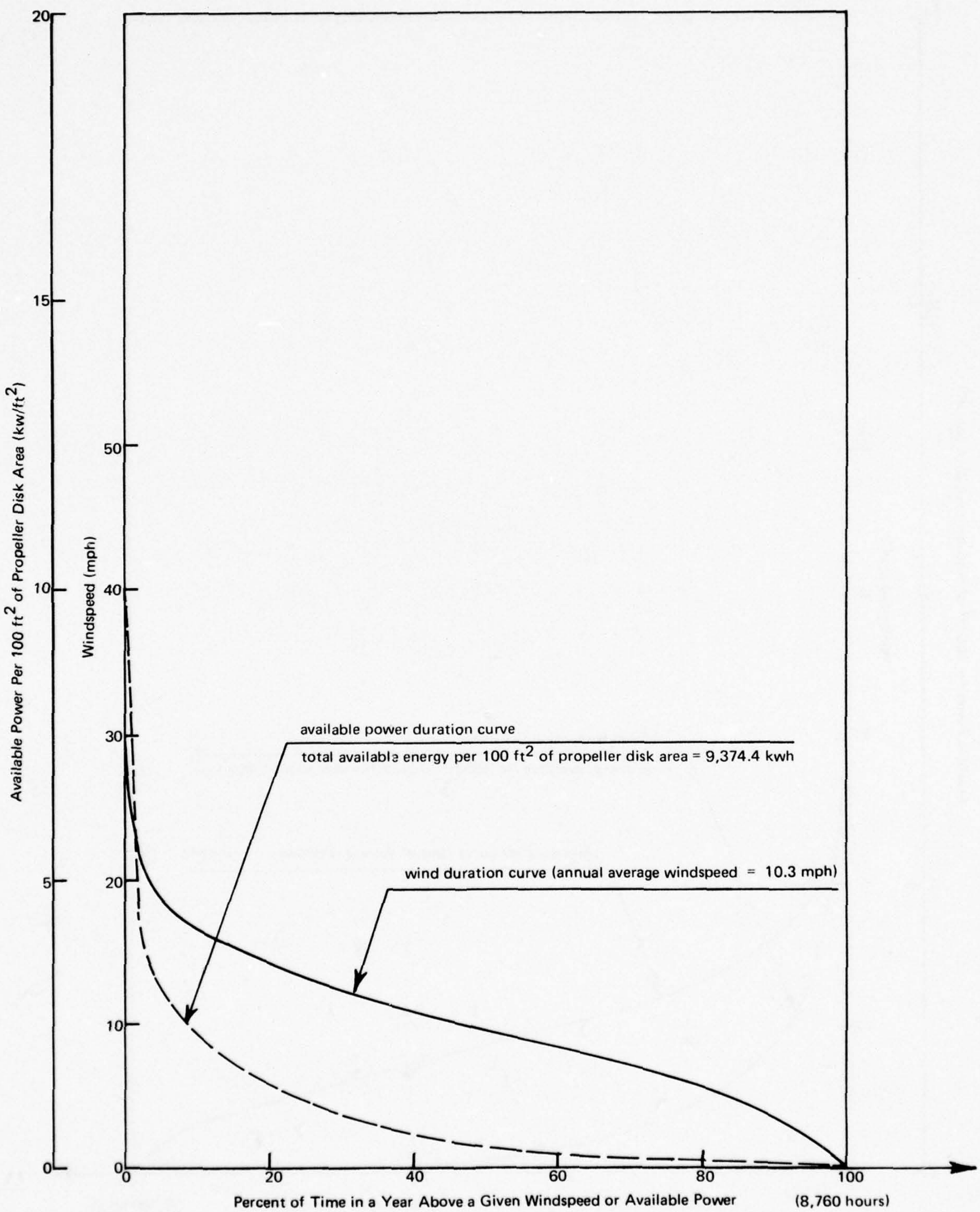

Figure 9. Windspeed and power duration curves for a site near Detroit

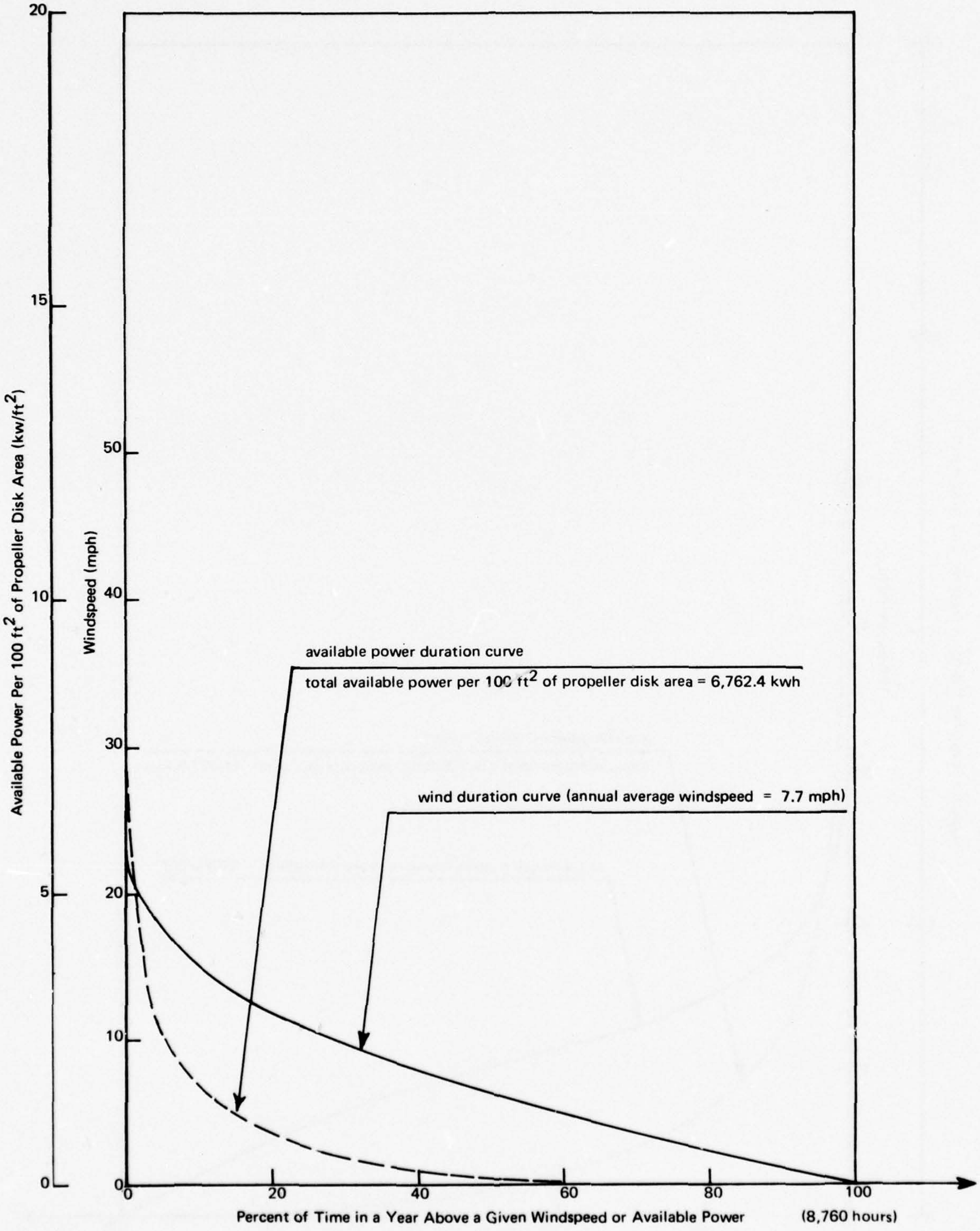

Figure 10. Windspeed and power duration curves for a site near Portland

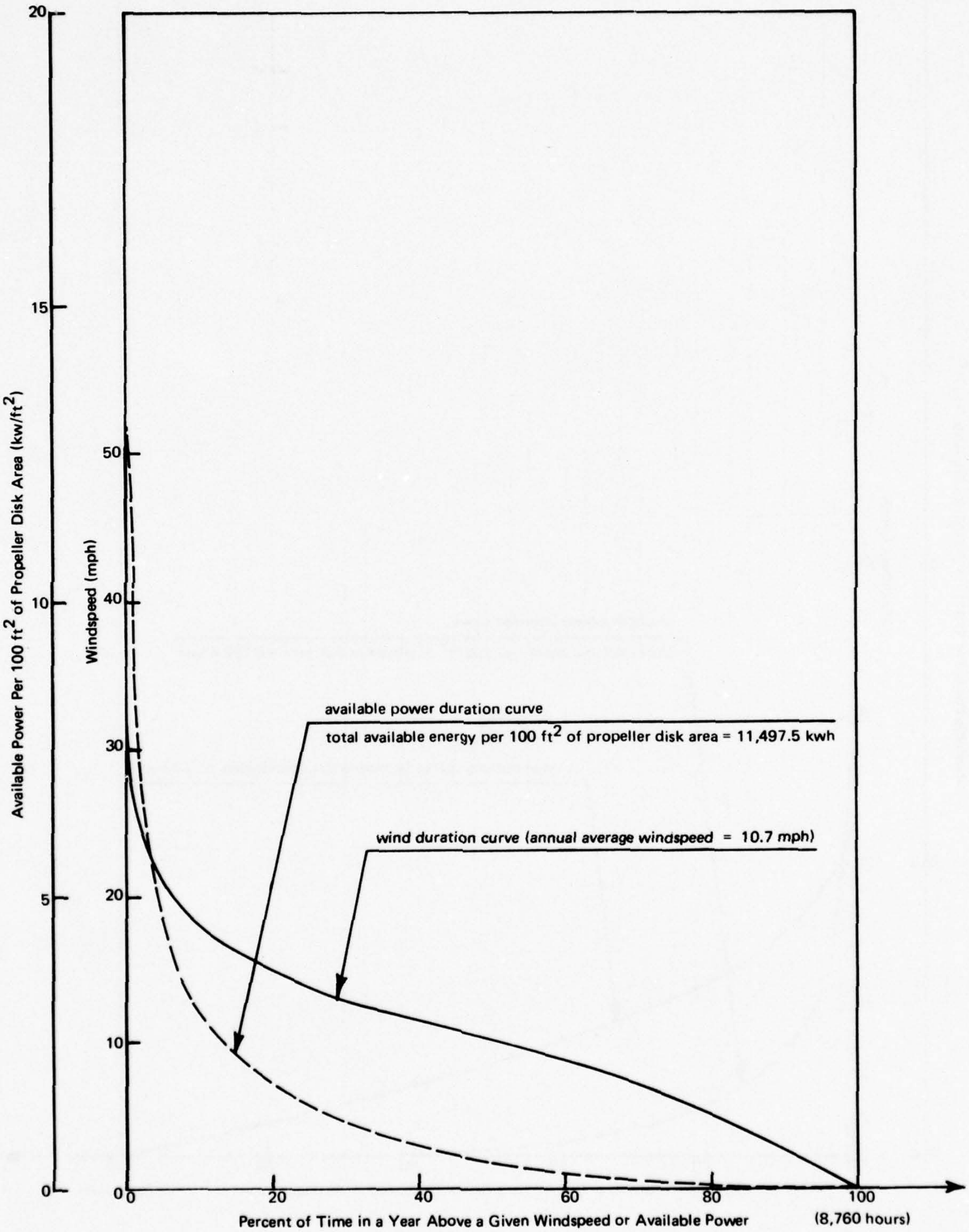

Figure 11. Windspeed and power duration curves for a site near Seattle (Tacoma Airport)

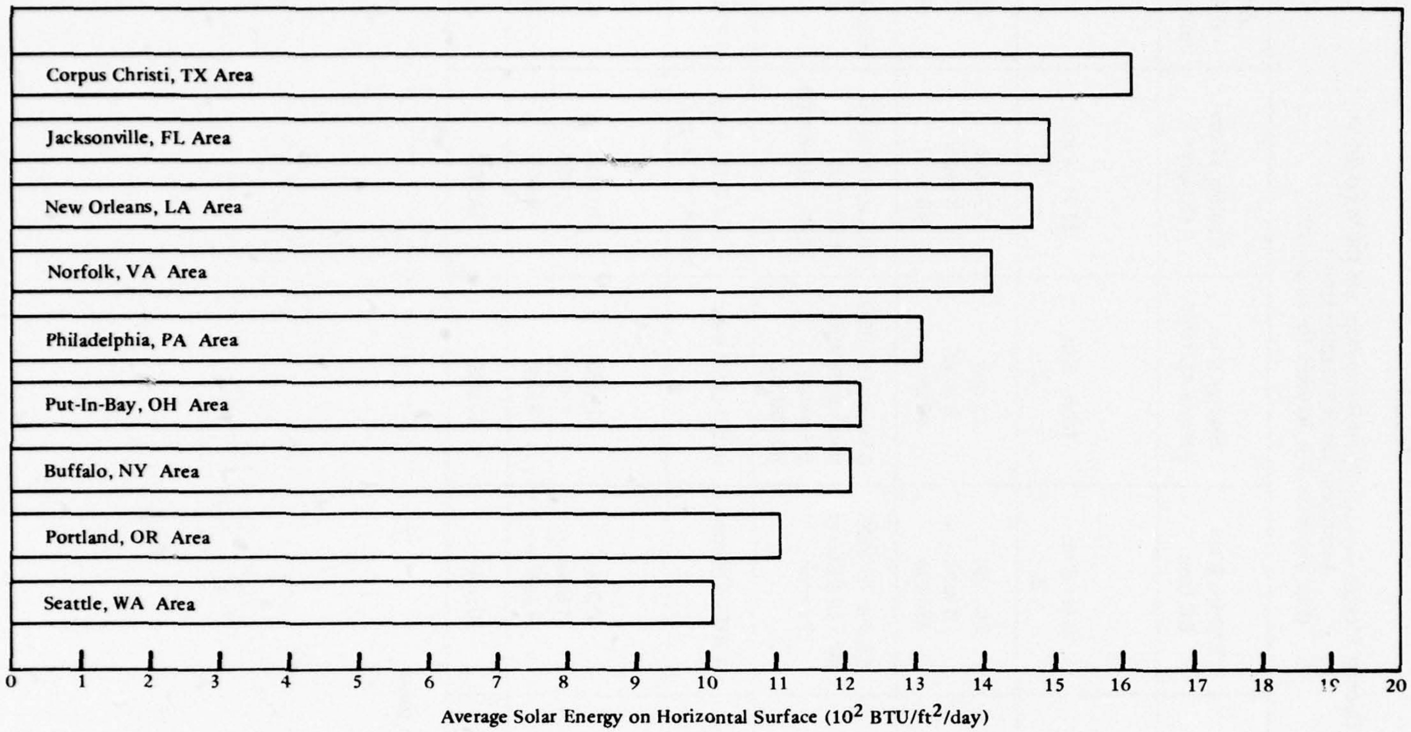

Figure 12. Daily average of annual available solar energy

Table 1

Data on Elektro G.m.b.h. Wind Generators and the Wind-driven Aeromotor Water Pumping Unit
(Life expectancy is 30 years for all units.)

Item	Elektro 6 kw DC Unit	Elektro 5 kw 3 Phase AC Unit	Elektro 12 kw DC Unit	Aeromotor 6-hp Water-pumping Unit
Propeller:				
diameter	16 ft - 5 in.	16 ft - 5 in.	21 ft - 6 in.	16 ft
no. of blades	3	3	3	18
Rated Windspeed	26 mph	23 mph	27 mph	25 mph
Cut-in Speed	8 mph	8 mph	8 mph	8 mph
Furling Speed	45 mph	45 mph	45 mph	45 mph
Output	6 kw at 65 VDC (or 115 FCD) at 26 mph	5 kw at 110/190 VAC at 23 mph frequency 60-100 Hz	10 kw, 110 VDC at 27 mph 12 kw, at 32 mph	6 hp at 25 mph
Power Coefficient C_p	0.307 at 26 mph	0.370 at 23 mph	0.267 at 27 mph 0.200 at 32 mph	0.272 at 25 mph
Cost ($)				
wind generator	6,700	6,700	10,000	5,000[a]
tower	1,800	1,800	2,000	
installation	2,000	2,000	2,000	2,000
Total ($)	10,500	10,500	14,000	7,000

[a]Including pump and tower

Table 2

Sample[a] of Predicted Monthly and Annual Performance of the 5-kw Elektro Wind Generator
(Mean monthly output of the unit = 901 kw-hr)

Performance Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Available Energy, kw-hr	3701	3396	4291	3369	2342	2150	1935	1738	2055	2345	3194	3658	35,209
Output, kw-hr	1130	1040	1175	1015	790	725	665	595	690	765	975	1110	10,815
Specific Power Output, kw-hr per kw-yr	226	208	235	203	158	145	133	119	138	153	195	222	2,163
Average Power Coefficient	0.305	0.306	0.274	0.301	0.337	0.337	0.344	0.342	0.336	0.326	0.305	0.303	0.307
Maximum Energy Excess or Deficiency of Above or Below the Monthly Mean and the Months in Which it Occurs.	0	0	276	0	0	0	0	-306	0	0	0	0	0

[a] Buffalo, New York.

Table 3

Summary of the Total Annual Output and the Specific Power Output of the Three Elektro Wind Generators for all the Nine Sites

Location	Annual Average Windspeed (mph)	5-kw, 3-Phase AC Unit		6-kw DC Unit		12-kw DC Unit	
		SPO[a]	Output kw-hr	SPO	Output kw-hr	SPO	Output kw-hr
Buffalo	12.4	2163	10,815	1849	11,094	1605	19,260
Galveston	12.5	2015	10,075	1768	10,609	1533	18,396
Seattle	10.7	1637	8,185	1387	8,322	1196	14,352
Detroit	10.3	1367	6,835	1153	6,918	992	11,902
Norfolk	10.2	1422	7,110	1145	6,870	985	11,820
Mobile	10.0	1276	6,380	1076	6,456	926	11,112
Philadelphia	9.6	1218	6,090	1028	6,167	885	10,620
Portland	7.7	873	4,365	804	4,823	693	8,316
Savannah	8.4	823	4,150	689	4,134	591	7,092

[a] SPO = units of kw-hr per kw-yr.

Table 4

Equipment and Installation Costs of Electrical Output
Produced by Elektro Units
(The initial costs per kw-hr do not include the interest on the capital.)

Location	6-kw DC Unit ($/kw-hr)	5-kw, 3 Phase AC Unit ($/kw-hr)	12-kw DC Unit ($/kw-hr)
Buffalo	0.0317	0.0323	0.0243
Galveston	0.0330	0.0347	0.0253
Seattle	0.0420	0.0427	0.0327
Detroit	0.0507	0.0513	0.0393
Norfolk	0.0510	0.0493	0.0393
Mobile	0.0543	0.0550	0.0420
Philadelphia	0.0567	0.0573	0.0440
Portland	0.0727	0.0803	0.0560
Savannah	0.0847	0.0843	0.0657

Table 5

Local Source Data on Daily Averages of Solar Energy for Selected Sites

	Langleys/Day for following sites --								
Time	Galveston District (Corpus Christi, TX Data)	Savannah District (Jacksonville), FL Data)	Mobile District (New Orleans, LA Data)	Norfolk District (Norfolk, VA Data)	Philadelphia District (Philadelphia, PA Data)	Detroit District (Put-in-Bay, OH Data)	Buffalo District (Buffalo, NY Data)	Portland District (Portland, OR Data)	Seattle District (Seattle, WA Data)
Jan	262	267	237	208	175	126	110	90	70
Feb	330	346	296	270	242	204	201	162	124
Mar	413	423	393	372	347	302	282	270	244
Apr	474	514	479	477	425	386	366	375	360
May	561	556	539	540	493	468	506	492	446
Jun	604	525	549	572	554	544	573	469	471
Jul	629	522	502	550	538	561	550	539	501
Aug	558	476	491	481	465	487	465	461	431
Sep	470	383	418	398	388	382	377	354	310
Oct	408	331	389	310	293	275	250	209	174
Nov	285	274	269	223	191	144	138	111	90
Dec	240	230	220	184	152	109	110	79	59
Annual Langleys	436	404	399	382	355	332	327	301	273
Annual BTU/ft^2	1609	1491	1472	1410	1310	1225	1208	1111	1007

APPENDIX F: NOTATION

A	Disk area through which fluid (wind or water) is moving
A'	Surface area under consideration, ft^2
A_p	Projected (in the current direction) area
C	Wind-power constant evaluated from long-term wind data
C_p or $C_p(V)$	Wind-power coefficient
c	Specific heat of substance
dt	Temperature differential
E	Energy
E_w	Total energy output
F	Frequency of the grid supply
G	Amount of water stored, gal
g	Acceleration of gravity (32.2 ft/sec^2)
H_s	Significant wave height, the average height of the highest third of the waves
h_{conv}	Convective heat transfer coefficient, Btu/hr-ft^2-^oF
m	Mass of substance
N	Design speed of the grid motor
P	Atmospheric pressure, lb/in.^{2}
P'	Number of poles in the field winding of the grid supply
P_a	Partial pressure of water vapor in air at air temperature (t_a), lb/in.^{2}
P_C	Power potential of water currents
P_{rated}	Rated output of wind machine using power duration curves
$P(t)$	Wind power per unit time
P_w	Vapor pressure of water at water temperature (t_w), lb/in.^{2}
$P_{w'}$	Power per foot of wave front width, kw
$P_W(t)$	Instantaneous power output of a wind machine
Q	Energy, Btu
RA	SR_i/SE_h ratio
SE_h	Average daily solar radiation received on a horizontal surface, ly/day

SE_o	Average daily extraterrestrial solar radiation received on a horizontal surface, ly/day
SPO	Specific power output, the ratio of the total annual output of the wind-power plant to its rated output
SR_i	Average daily solar radiation received on a south-facing surface (angle from horizontal), ly/day
s	Slip of the grid supply
T	Time period
T'	Wave period
TA	Time adjustment, min
t	Time
t_f	Final temperature of substance, ^oF
t_i	Initial temperature of substance, ^oF
U	Mean windspeed
V'	Heat of vaporization of water, Btu/lb
V	Windspeed
V(t)	Windspeed at given instant of time t
v	Current velocity
W	Humidity ratio
W'	Width of wave front
Z	Amount of water vapor in lb/hr
γ	Weight density of fluid (62.4 lb/ft^3 for fresh water and 64 lb/ft^3 for seawater)
ε	Energy dissipation rate in ft^2/sec
η	Overall efficiency
ρ_a	Mass density of air
ρ_w	Mass density of fluid (2 $lb\text{-}sec^2/ft^4$ for seawater)
$\phi(U,T)$	Energy pattern factor
$\phi_A(U)$	Asymptotic value of $\phi(U,T)$

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Parker, C E

Identification of alternative power sources for dredged material processing operations / by C. E. Parker ... [et al.], Civil Engineering Laboratory, Naval Construction Battalion Center, Port Hueneme, California. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1977.

60, [77] p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; D-77-32)

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IDENTIFICATION OF ALTERNATIVE POWER SOURCES

FOR

DREDGED MATERIAL PROCESSING OPERATIONS

APPENDICES A-E

TR D-77-32

APPENDIX A: WIND POWER ANALYSIS METHODOLOGIES AND CONVERSION SYSTEMS

Analysis Methodologies

Wind energy calculations

1. The instantaneous power available in the wind is the kinetic energy per unit time of a column of air moving undisturbed through a finite disk area. Explicitly, the power P(t)* is

$$P(t) = \frac{1}{2} \rho_a A V^3(t) \tag{A1}$$

where ρ_a = the mass density of air

A = the disk area through which the wind is blowing

V(t) = the windspeed at a given instant of time t

In Equation A1, the changes in the ambient air density ρ_a due to daily and seasonal temperature variations are considered to be small; thus, these changes will be considered as independent of time at a given location. Integrating Equation A1 over time t yields the energy available in the wind over an arbitrary period of time (e.g., T). Thus, the energy E is

$$E = \int_0^T P(t)dt = \frac{1}{2} \rho_a A \int_0^T V^3(t)dt \tag{A2}$$

Since V(t) is available as a set of numbers, E is generally obtained by numerical evaluation of the integral. A standard numerical integration technique, such as trapezoidal rule, yields fairly accurate results.

2. A wind machine can convert only a fraction of the available power into the shaft output, thus implying that the expression of Equation A1 must be multiplied by a conversion factor to obtain the power

* For convenience, symbols and unusual abbreviations are listed and defined in the Notation of Appendix F.

output of the wind machine. The theoretically limiting value of the conversion factor for a propeller machine is 0.593. Thus, the instantaneous power output of a given wind machine at V(t) is

$$P_W(t) = \frac{1}{2} C_p(V) \rho_a \; A \; V^3(t) \qquad \text{(A3)}$$

where the factor $C_p(V)$ is called the "power coefficient" of the machine. For a conventional propeller machine, depending upon the windspeed V(t), $C_p(V)$ varies from 0.4 to 0. Finally, the total energy output E_w of a wind machine over a time period T is

$$E_w = \frac{1}{2} \rho_a \; A \int_o^T C_p(V) \; V^3(t) dt \qquad \text{(A4)}$$

3. Further, the power coefficient $C_p(V)$ for a given wind machine is easily obtainable from its design and performance characteristics by solving Equation A3 for $C_p(V)$. As an example, $C_p(V)$ for a commercially available 5-kw wind generator was computed; the results appear in Table A1. A plot of $C_p(V)$ versus V for the same machine is shown in Figure A1. The values of $C_p(V)$ for windspeed values at or below 7 mph are zero because the wind machine has a cut-in speed of 8 mph. The machine starts producing the full output of 5 kw at a windspeed of 23 mph and has a furling (shut-down) speed of 45 mph to protect it against storms and gales.

4. Specific power output (SPO) is a commonly used variable for evaluating the performance of wind machines. For a given location it is defined as the ratio of the total annual output of the wind-power plant to its rated output. Since the annual output is generally measured in kw-hr and the rated output of the machine is specified in kw, the SPO is stated in units of kw-hr/kw-yr. By analytically using Equation A4, SPO for a wind machine installation is given by

$$SPO = \frac{\frac{1}{2}\rho_a A \int_0^T C_p(V)\, V^3(t)dt}{P_{rated}} \qquad (A5)$$

where P_{rated} is the rated output of the machine using power duration curves. The integral in Equation A5 can be evaluated numerically. Physically, the SPO for a given installation indicates the number of hours of rated output operation in a year. A high value of SPO indicates a good installation while a low SPO implies poor installation. Thus, the SPO plays an important role in appraising a site for wind power installation.

Windspeed and power duration

5. Existing surface wind data in the form of windspeed, usually given in miles per hour or knots, are measured by an anemometer, with observations made each hour. Another way of presenting wind data for a given location is to prepare drawings of monthly or annual frequency distribution of windspeed and direction, called "wind roses." The wind data are compiled as percentage frequency of windspeed and direction groups. To a wind-energy analyst the frequency of wind direction at a given location may be important in sizing a given wind machine, but for estimation of the output of the machine at the location over a certain period of time, the wind direction is of little importance. Thus, for this study, the wind data for each site are listed as a total of frequencies for all directions. Table A2 is an example of the format of the historical wind data available from National Climatic Center. The data are given by the month and the year as a percentage of frequency of windspeed in a given speed or range. The data in the tables were based on the observations taken during 1951 to 1960.

Descriptions of Conversion Systems

6. The windmill-driven reciprocating pumps generally are designed to handle relatively small amounts of water at high lifts for transferring the water to elevated tanks. At dredged material containment

sites, pumping systems capable of transferring large quantities of fluid against low to moderate heads are required. Most of such pumping units are required to handle headed water containing a wide variety of solids, including silts, clays, and inorganic matter. Further, if such pumps were driven by wind-power sources, they would operate under variable input torque. Generally, the variable torque input to the pump shaft results in a variable speed operation which in turn causes higher losses of energy. Presently, no off-the-shelf pumping hardware is suitable for pumping muddy water and, at the same time, compatible with the wind turbine output. However, wind-generated electricity offers more flexibility in operating equipment and systems at the sites.

7. Another factor to be considered while applying wind power at the dredged material site is construction cost of installing the wind-power installation. At most sites, locating a wind-power system may require special foundation design due to the poor bearing capacity of the local soil. Special construction features may result in additional costs and thus raise the cost of the power produced on a per kilowatt-hour basis. Additional research is necessary to fully assess the practical utilization of wind power at dredged material sites.

8. For dewatering dredge containment sites comprised mostly of sand, the conventional pump designs of either the reciprocating or the centrifugal type may suffice. Price Island in the Portland District (Appendix D) is an example of such a site, which occupies a land area of about 120 acres. Preliminary calculations show that two 16-ft-diam Aeromotor pumping units are enough for dewatering the Price Island site.

9. Sectorov[4] suggested that to use wind power for water pumping and irrigation installation, it is generally most convenient to operate the centrifugal pump electrically from the output of a wind generator. Such an arrangement ensures nearly constant-speed operation of the pump without deteriorating its efficiency. Also, direct conversion of wind energy into electricity offers more flexibility in its usage. For

example, if the electro-osmosis method of dewatering is applied at a site, the wind-generated electricity may be used for the electrodes and for operating the water pump simultaneously.

10. Because of the random nature of the wind, an AC generator driven by a wind-powered rotor will deliver electricity with variable voltage and frequency. The variable frequency power, if supplied to a motor driving the water lift pump, will operate it at irregular speeds. To keep the cost of the energy produced low, it is essential to fully utilize the output from the wind generator. That is, utilization of the generated power between cut-in and rated speed must be done by matching the load to the generator's momentary capacity. Thus, to follow the generator's output versus windspeed characteristics over its entire operating range, the available load should be infinitely variable. In practice, however, the infinitely variable load is almost impossible to obtain. One convenient way is to divide the available load into a series of small units and switch them in and out of the circuit to match the generator's instantaneous output. Such a scheme requires an automatic switching device for applying the load to the generator circuit. One such system employs electromechanical relays for load switching and is now under development at CEL, as shown in Figure A2. The switching relays used are controlled by an electronic logic circuit actuated by the generator output. In the operation of the switching device, the plots of Figure A3 show that the various switching sequences are a function of the generator output frequency for a five-step switching device. The schematic also shows that a rectifier converts the output of the 3-phase AC generator into a DC power required by the electrodes of the electro-osmosis process. The loads L1, L2, etc., refer to a bank of electrodes at convenient locations at the site. In fact, the concept of the switching devices discussed can be easily extended to a system for sharing the load with the existing utility or other source of electricity simply by using two-position relays as shown in Figure A4. An

additional rectifier is required on the utility line to obtain DC electricity. During the period the wind generator is inoperative, the electrodes are supplied by the utility power and when the wind is blowing above the cut-in speed of the wind generator, the switching device connects the optimum number of electrodes to the generator. This arrangement provides an efficient use of the wind generator's output while maintaining continuity of power to the electrodes. One of the loads in the schematic of Figure A2 may be the motor of a pump required to lift water after it is collected at the cathode. The power input to the pump motor may be AC and need not be rectified. A concept to accomplish constant speed operation of an AC motor operated on the variable output of the wind generator will be discussed next.

11. Figure A5 is a schematic of a system for mixing the grid and the wind-generated power mechanically to drive a centrifugal pump at constant speed. The pump is driven by two motors coupled to its shaft. One motor is a variable pole-induction motor connected to the grid line. Irrespective of the windspeed, the pump operates at a constant speed corresponding to the design speed of the grid motor given by

$$N = 120F(1-s)/P' \qquad \text{(A6)}$$

where F = the frequency in Hz of the grid supply

s = the slip, which usually varies from 0.02 to 0.10 depending on the motor size

P' = the number of poles in the field winding

The arrangement locks the wind-generator rotor to a speed corresponding to N. Thus, the changes in windspeed will result in a variable tip-speed-to-windspeed ratio of the rotor. For maximum efficiency, most commercial wind machines must operate at a fixed tip-speed-to-windspeed ratio. Hence, the rotor of a wind machine must turn at variable speed to maintain its tip-speed-to-windspeed ratio close to its rated value. One method of optimizing this ratio is to allow a discrete change in the

rotor speed in various steps by changing the poles on the motor at some preselected windspeeds. The pole changing can be done by an automatic switching device of the type discussed earlier. The concept being discussed uses four or five different pole pairs in the range between the cut-in and the rated speed of the rotor. In practice, doubling the number of poles can be done by a simple parallel circuit scheme. Further investigation, however, is required to prove the practicability of the method.

12. Another system for dewatering dredged material processing sites is shown schematically in Figure A6. The system is simple and uses off-the-shelf components. The lifting of the water is done by a positive displacement device of reciprocating type, such as a diaphragm pump. To utilize the wind machine output efficiently, a set of two holding tanks is provided: as one is emptied, the other stores the water being lifted. The system has a special advantage in that the lift pump never comes in contact with the water being lifted. The various valves on the lines are electrically operated through some type of level sensor in the holding tanks. The lift pump is driven by a wind machine through a mechanical coupling. The practicality of the system should be determined through field tests at a site where dewatering is a definite problem (e.g., at Mobile).

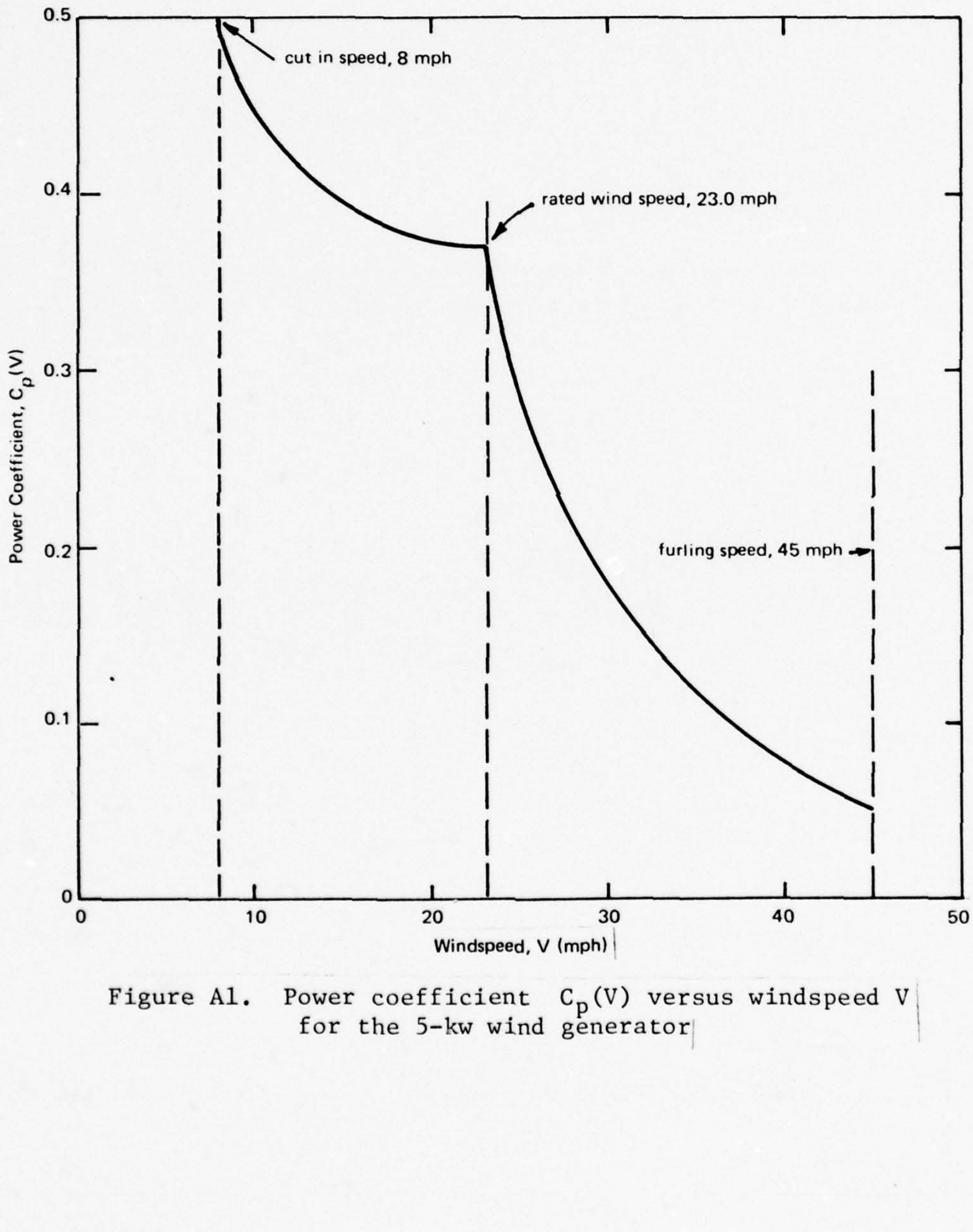

Figure A1. Power coefficient $C_p(V)$ versus windspeed V for the 5-kw wind generator

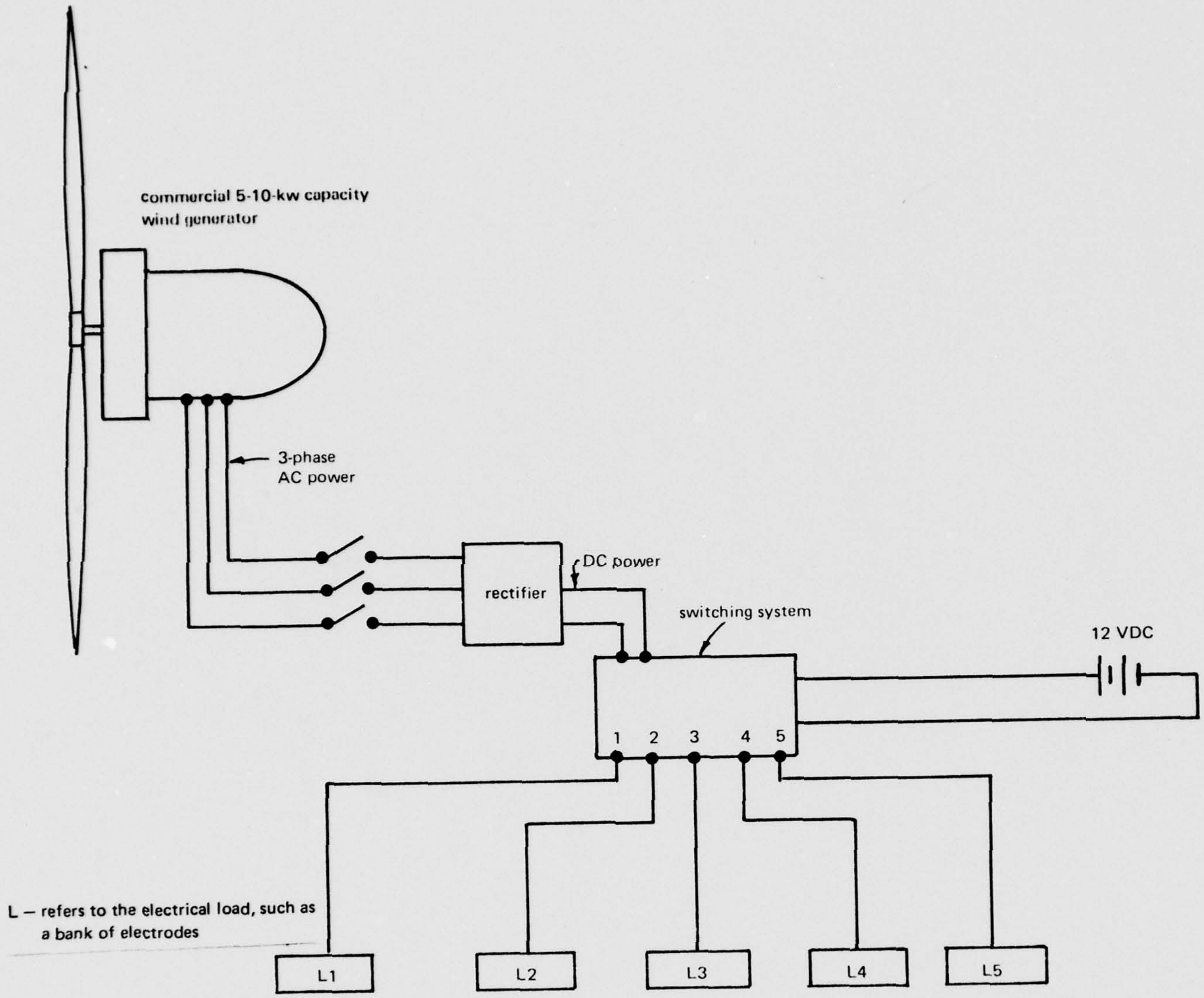

Figure A2. Operating a 3-phase AC wind generator with an automatic switching device for electro-osmotic dewatering

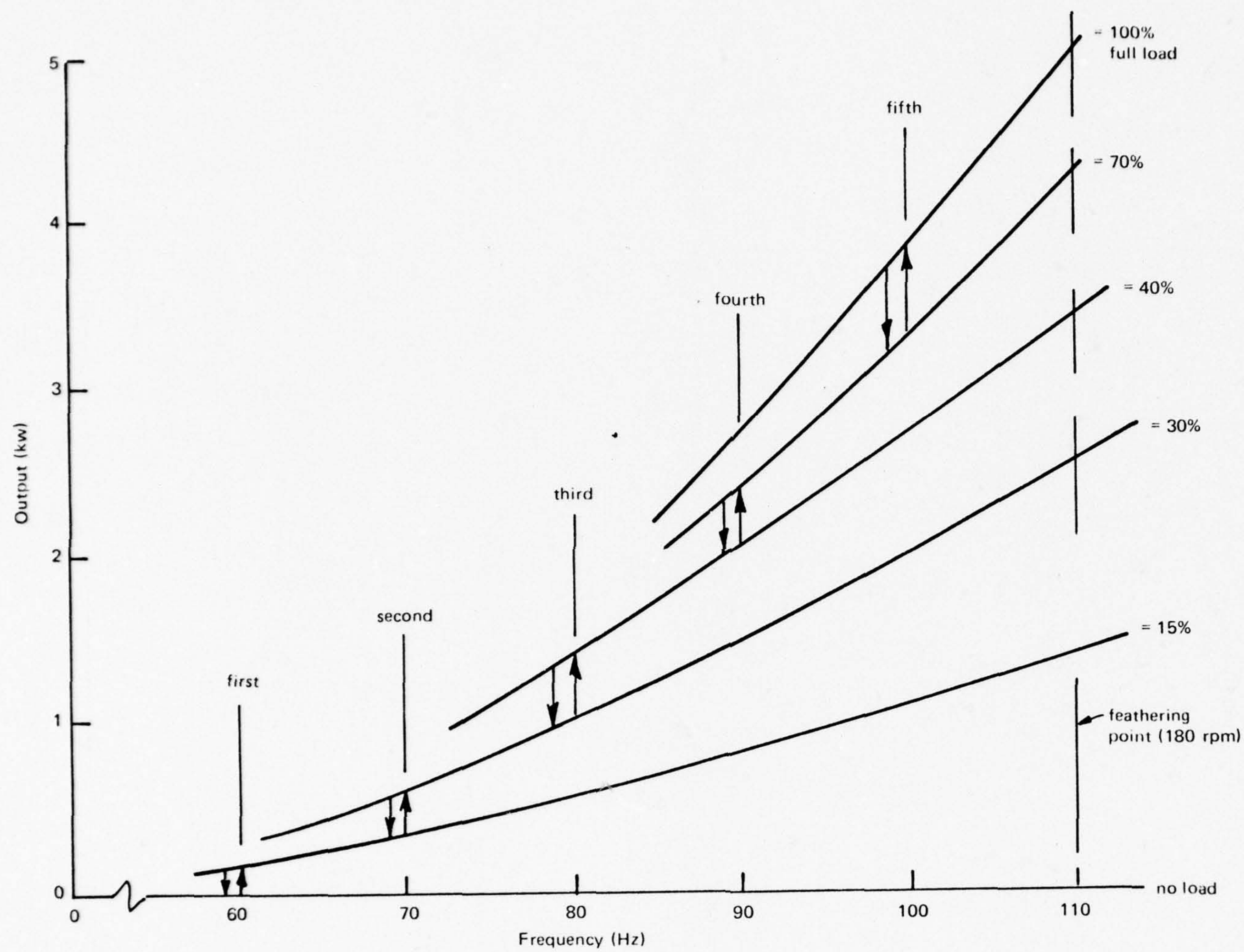

Figure A3. Characteristics of 5-kw electro wind generator and switching system for optimal usage of wind energy

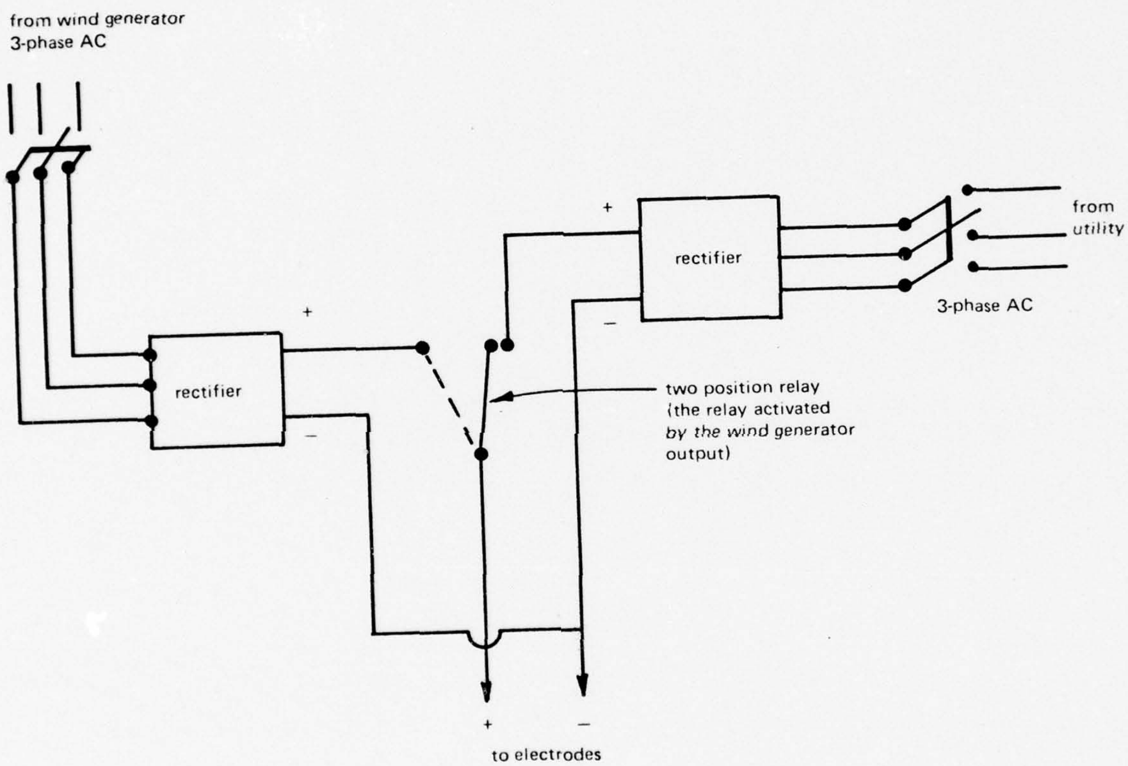

Figure A4. Sharing wind-generated power with commercial power for continuous electro-osmotic dewatering

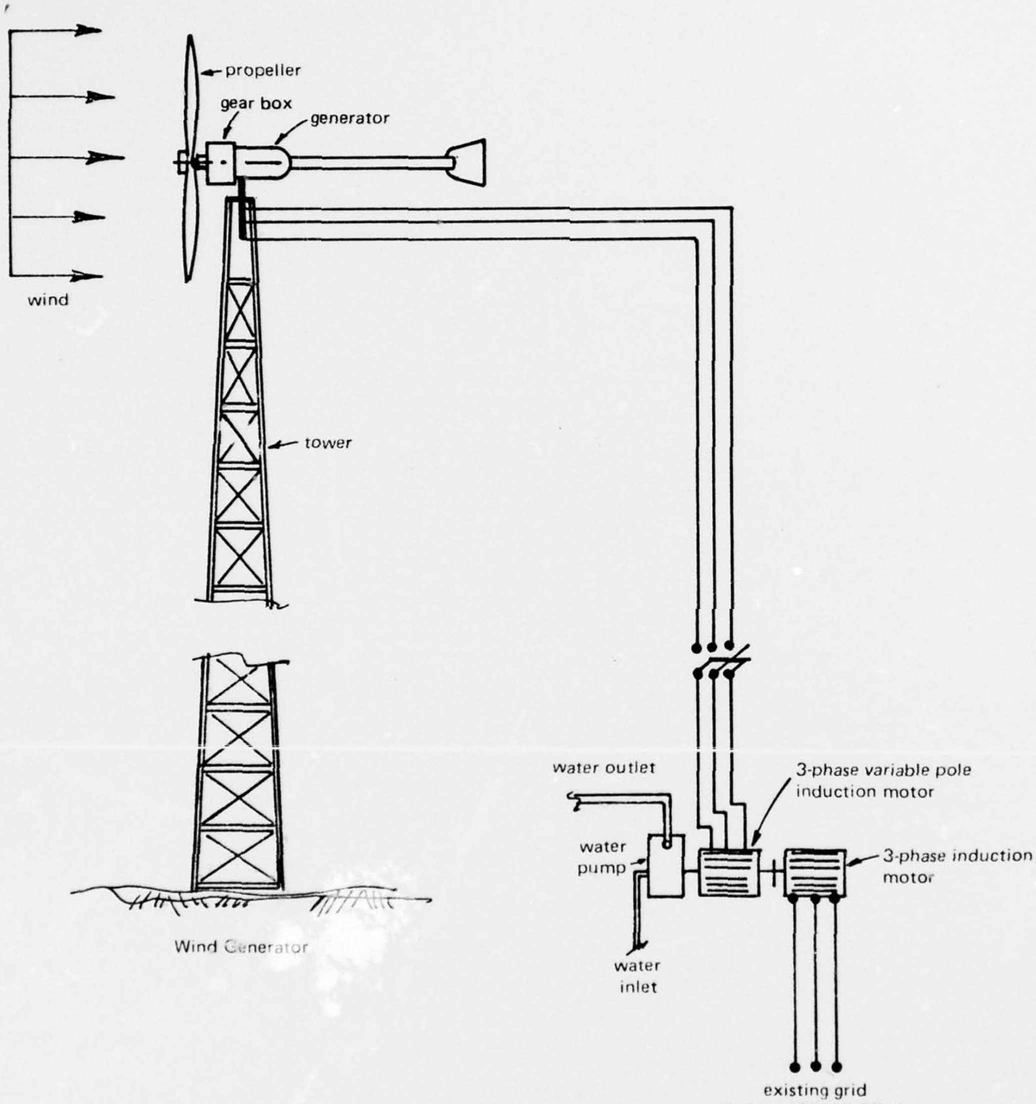

Figure A5. Method of using wind-generated power with grid power for pumping water at constant speed

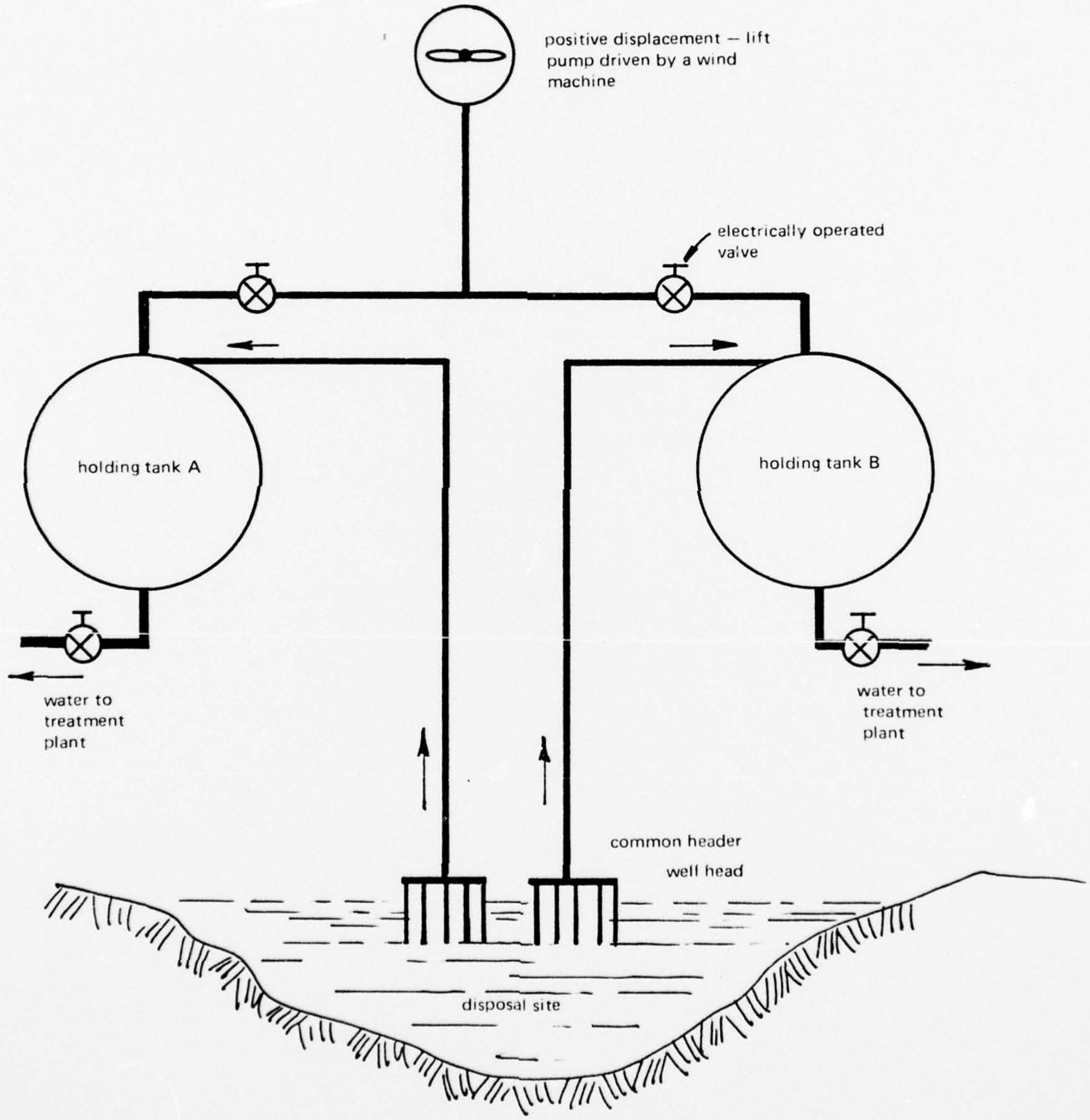

Figure A6. Windmill-driven diaphragm pump system for dredged material dewatering

Table A1

Power Coefficient $C_p(V)$ for a 5-kw Commercial Wind Generator for Various Windspeeds

Windspeed, mph	Power Coefficient, $C_p = \frac{P_W(t)}{\frac{1}{2}\rho_a A V^3(t)}$
0	0
3	0
7	0
10	0.443
12	0.417
15	0.390
18	0.376
23	0.370
24	0.343
31	0.163
38	0.09
46	0

Table A2

Frequencies of Windspeed in the Vicinity of Buffalo, New York

Month	Frequencies (%) Based on Hourly Observations of Windspeed at Following mph - -										Average Wind-speed (mph)
	0-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	47 Over	Total	
January	4	13	30	30	17	5	1	+	+	100	13.5
February	3	12	30	32	17	5	1	+	0	100	13.9
March	4	13	30	28	16	6	2	1	+	100	14.1
April	6	16	29	28	15	5	1	+	+	100	13.2
May	5	18	36	27	11	2	+	+	0	100	11.9
June	5	19	38	25	10	2	+	+	+	100	11.6
July	7	21	37	24	9	1	+	0	0	100	11.1
August	8	23	39	22	7	1	+	+	0	100	10.5
September	6	20	39	24	9	2	+	+	0	100	11.1
October	5	20	39	23	10	3	+	+	+	100	11.5
November	4	15	32	27	15	4	1	+	+	100	13.3
December	4	15	28	29	17	5	1	+	+	100	13.5
Annual	5	17	34	27	13	3	1	+	+	100	12.4

APPENDIX B: SOLAR ENERGY CONVERSION PROCESSES

Descriptions of Conversion Systems

Types of systems

1. Solar-chemical. In the solar-chemical conversion process, the sun's energy is directly converted into chemical energy through electronic processes within the solar collecting medium. This is the basic mechanism of photosynthesis. It provides for growth of plants, which can be consumed by various methods to provide heat, electricity, nutrition, etc. Figure B1 displays a flow diagram of a typical solar-chemical energy conversion process designed for heating application.

2. The direct solar-chemical conversion process of plant growth (requiring water) could be utilized to eliminate moisture from unwanted areas; however, this approach necessitates both planting and harvesting operations and may involve a lengthy "plant growing" period. The basic solar-chemical energy conversion process is believed to offer limited results in energy reduction of dredged material processing operations.

3. Solar-thermal. The solar-thermal conversion process is the direct conversion of the sun's energy into usable heat. (This is the basic driving force of other energy forms — wind, hydropower, ocean thermal gradients, ocean currents, etc.) This process is commonly utilized for air drying of agricultural products, heating pool water, preheating potable hot water, and providing heated air into building conditioning zones.

4. An extension of the basic solar-thermal process is use of a heated fluid to provide power for: (a) operating an engine for a mechanical drive system and (b) operating a turbine for electrical generation. This latter energy conversion is designated the solar-thermal-electric process, which is presently being investigated as the process for future large-scale electrical generation. Figures B2 and B3 show typical flow diagrams of the solar-thermal and solar-thermal-electric energy conversion processes, respectively.

5. Solar-electric. A solar-electric process, more commonly known as the photovoltaic conversion, consists of electrical energy (direct current) being produced directly upon the collector's exposure to sunlight. The energy conversion system necessitates an inverter to achieve alternating electrical current status. Figure B4 shows a typical flow diagram of this process.

6. This type of system is still much in the development stage with regard to low cost applications. Systems that are in service are very expensive but acceptable for remote site (space, ocean) applications.

Solar Energy Conversion Equipment

Solar collectors

7. Flat-plate solar collector. The basic construction components of the flat-plate solar collector are

- a. Glazing cover — transparent glass or plastic cover to transmit sunlight and minimize heat loss via convection heat transfer.
- b. Absorber plate — principal solar heat collecting surface to which fluid tubes are attached.
- c. Fluid tube — provides for passage of heat-carrying medium.
- d. Insulation — to minimize heat losses from absorber plate/fluid tube.
- e. Casing — enclosure that houses the components.

Figure B5 depicts the components of the flat-plate collector; Figure B6 displays various cross sections that are commonly utilized in flat-plate solar collectors. Energy collection efficiency of flat-plate collectors depends upon construction and application, but will range between 40 to 90% for space cooling and low air temperature heating applications, respectively.

8. Solar concentrators. Concentrators are basically constructed with two surfaces: a reflector surface and a blackened receiving surface (fluid tube or boiler). Two major disadvantages with concentrators are their utilization of only the direct (not diffuse) component of sunlight

and their requirement that tracking devices follow the sun across the sky. Their energy collection efficiency depends upon construction and desired outlet fluid temperatures, but efficiency is generally less than 50%.

9. Solar cell. The solar cell consists of a positive-negative (P-N) junction in a semiconductor between a positive (P) layer, which contains movable positive charges, and a negative (N) layer, which contains movable electrons. When sunlight is absorbed by the cell, each photon unit of light produces a negative electron and a positive charge. Ordinarily, these would immediately recombine and result in the conversion of light to heat. However, due to the potential barrier at the P-N junction, the electrons produced by the light in the N-layer are driven to the electrode, and the positive charges produced by the light in the P-layer are driven to the other electrode. As these electrons and positive charges build up at the two separate electrodes, a potential develops and electrical current flows through the wires connecting the two electrodes. Figure B7 displays views of a typical photovoltaic solar cell.

10. Various materials are being utilized in the construction of solar cells to achieve high energy conversion efficiencies and lower manufacturing costs. Most notable of these materials are: silicon, cadmium sulfide, and gallium arsenide. To date, average energy conversion efficiency of solar cells is only about 10%.

Energy storage

11. Numerous forms of devices for storing collected sun energy are both available and currently being researched. The principal methods of energy storage discussed in this report are thermal and electrical.

12. Thermal storage is the most common and involves increasing a storage substance's temperature. Water is primary choice for thermal storage because of its ready availability and high heat capacity. Rocks provide a secondary storage selection but are chiefly used in air heating systems.

13. Electrical energy is stored principally in batteries charged during daylight hours. Several types are marketed, varying in operating life, charging rates, size, and costs. Some present day and future battery types are: lead-acid (liquid and dry), nickel-iron, nickel-zinc, nickel-cadmium, lithium-sulfur, and sodium-sulfur.

14. If batteries were to be used, they would be connected in parallel to allow low voltage charging by photovoltaic or solar-thermal-electric energy conversion devices and then would be discharged in series connection at higher voltages.

15. Fly-wheels, fuel cells, and other similar exotic energy storage devices are still in development; their applicability to dredged material processing operations is undetermined.

Ancillary equipment

16. To complete any solar energy conversion system, transmission, control and retrieval of the energy collected and stored must be considered. These topics will be briefly discussed below, with emphasis on solar-thermal system applications.

17. Transmission. The energy transmission system consists basically of: passage-ways for the heat-carrying medium and prime movers (e.g., water pump or air fan) of the heat transferring medium. Materials, size, and design of the passage-ways will be dependent upon: (a) the type of heat-carrying medium, (b) system pressure requirements, (c) corrosion particulars, (d) temperatures expected, and (e) desired flow rate capacity. For air transporting systems, plastic pipe/duct-work will satisfy expected system requirements; for liquid transporting systems, metal piping is principally utilized (plastic may be used in limited applications). Choice of metal piping — inexpensive steel to expensive copper — depends upon system design requirements.

18. Control. Controlling the operation of a solar energy conversion system is of paramount importance. The term "control" refers to switching on-off or modulating prime movers and terminal (energy retrieval) units. The latter are usually controlled by specifically located

temperature sensors. Temperature sensors are usually placed: (a) at the outlet of the collector system, (b) inside the energy storage medium, and (c) in the location designated for final disposition of the collected solar energy. The collector system operates when solar energy can be absorbed; the retrieval system activates when collected or stored solar energy is needed.

19. Retrieval. Retrieving the collected or stored solar energy may require terminal equipment (heat exchanger) to transform this energy into a usable form. Fan coil units (water-to-air heat exchanger with fan assembly) are typically used to convert heat from a liquid to an airstream. Where air is heated in the solar collector and utilized directly, as in the case of enhancing dredged material dewatering, no terminal unit is required.

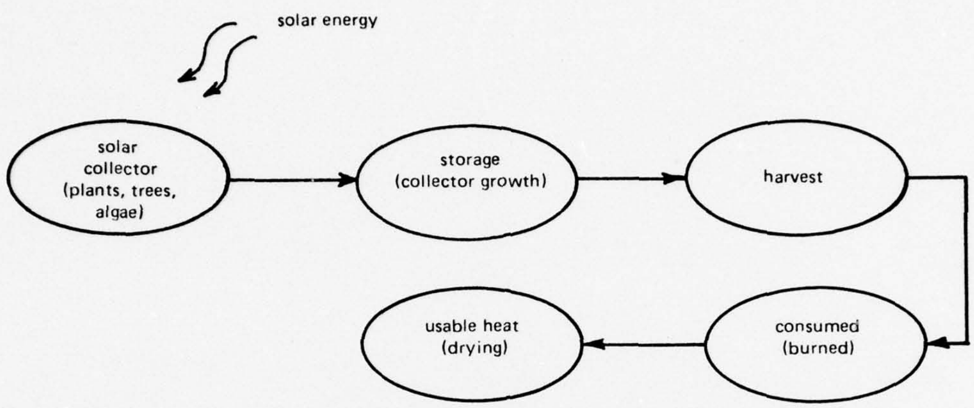

Figure B1. Typical solar-chemical energy conversion process

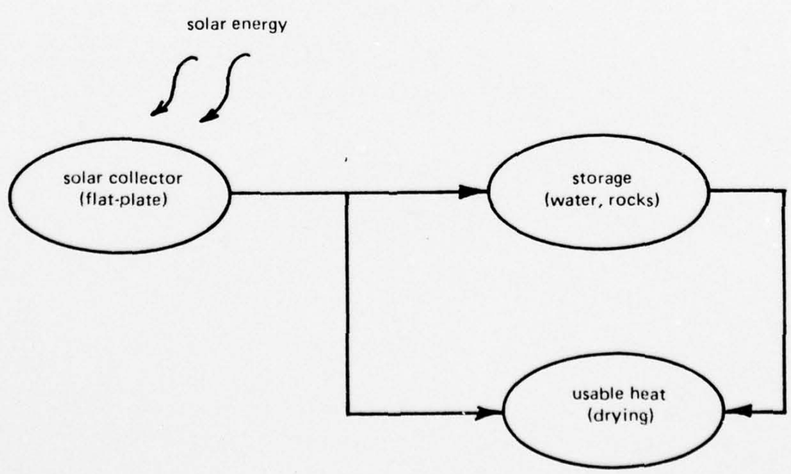

Figure B2. Typical solar-thermal energy conversion process

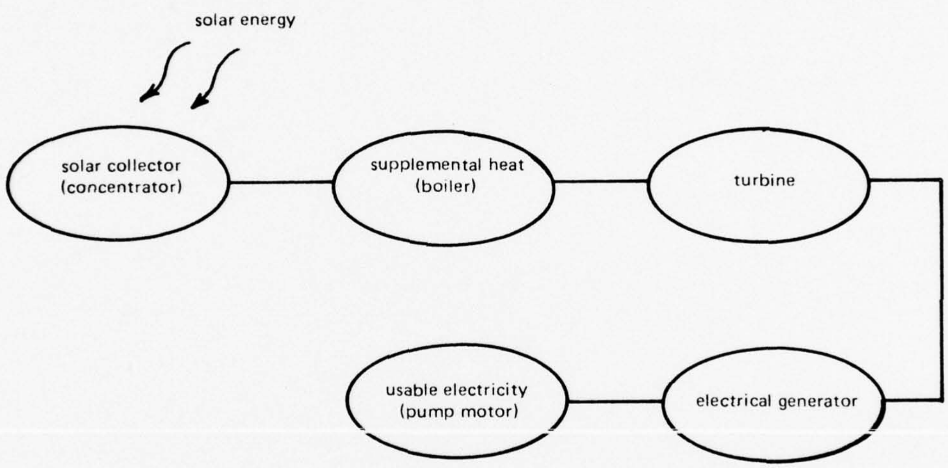

Figure B3. Typical solar-thermal-electric energy conversion process

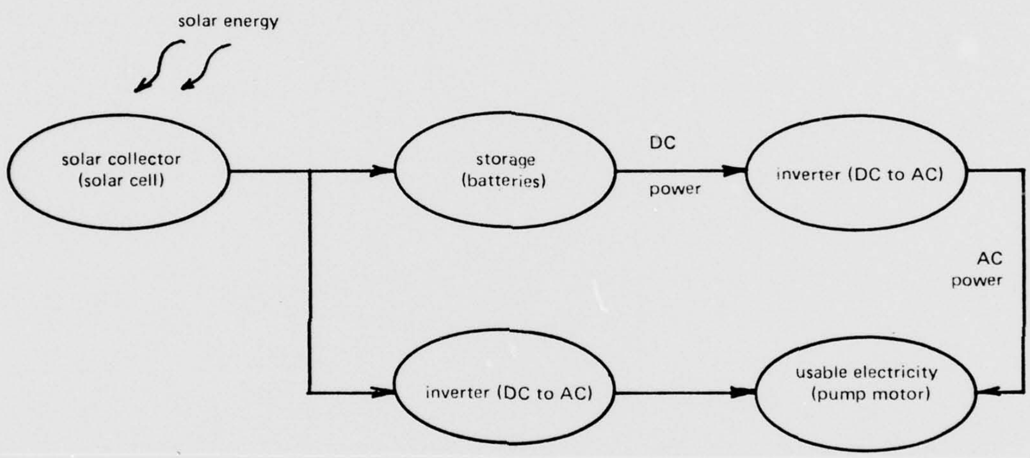

Figure B4. Typical solar-electric energy conversion process

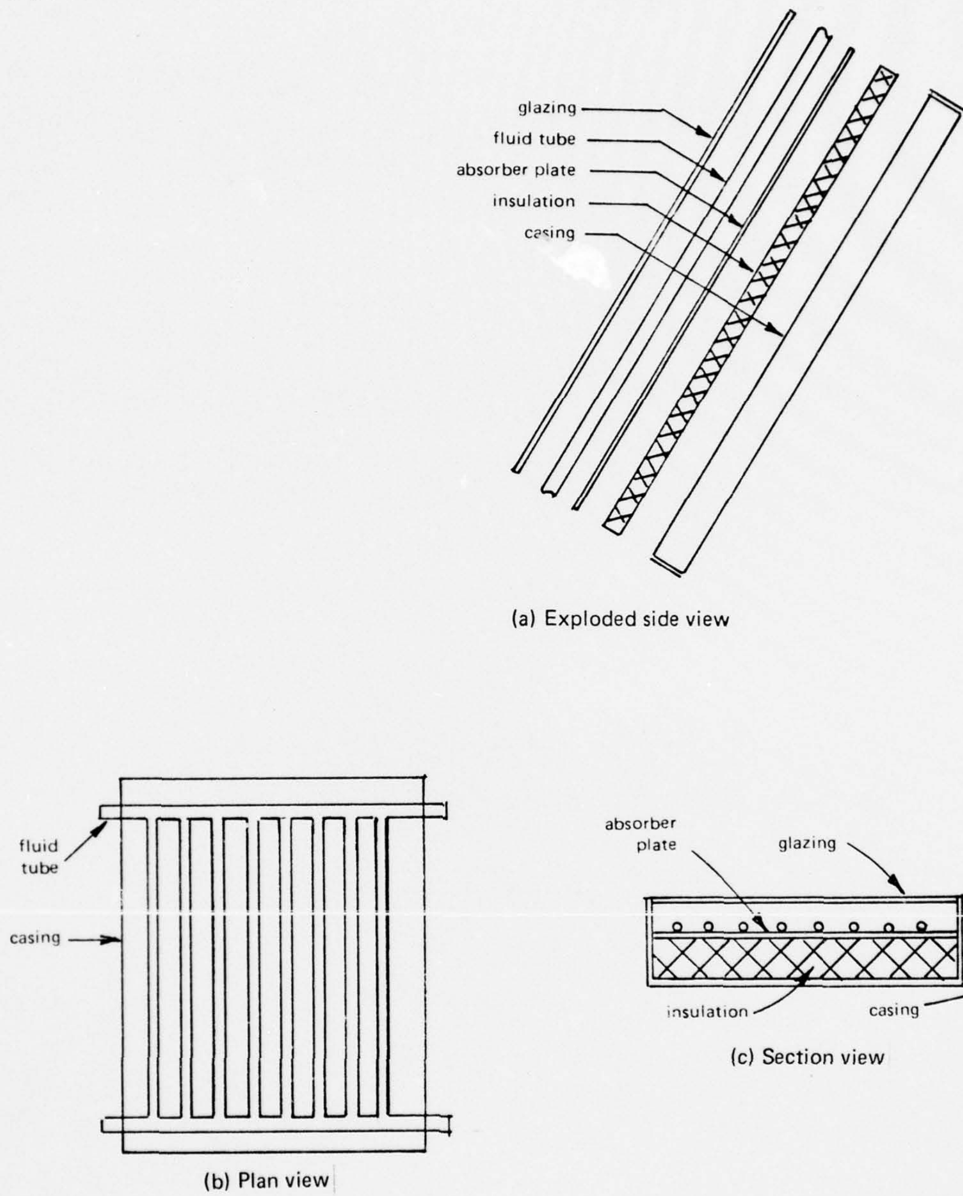

Figure B5. Typical flat-plate solar collector

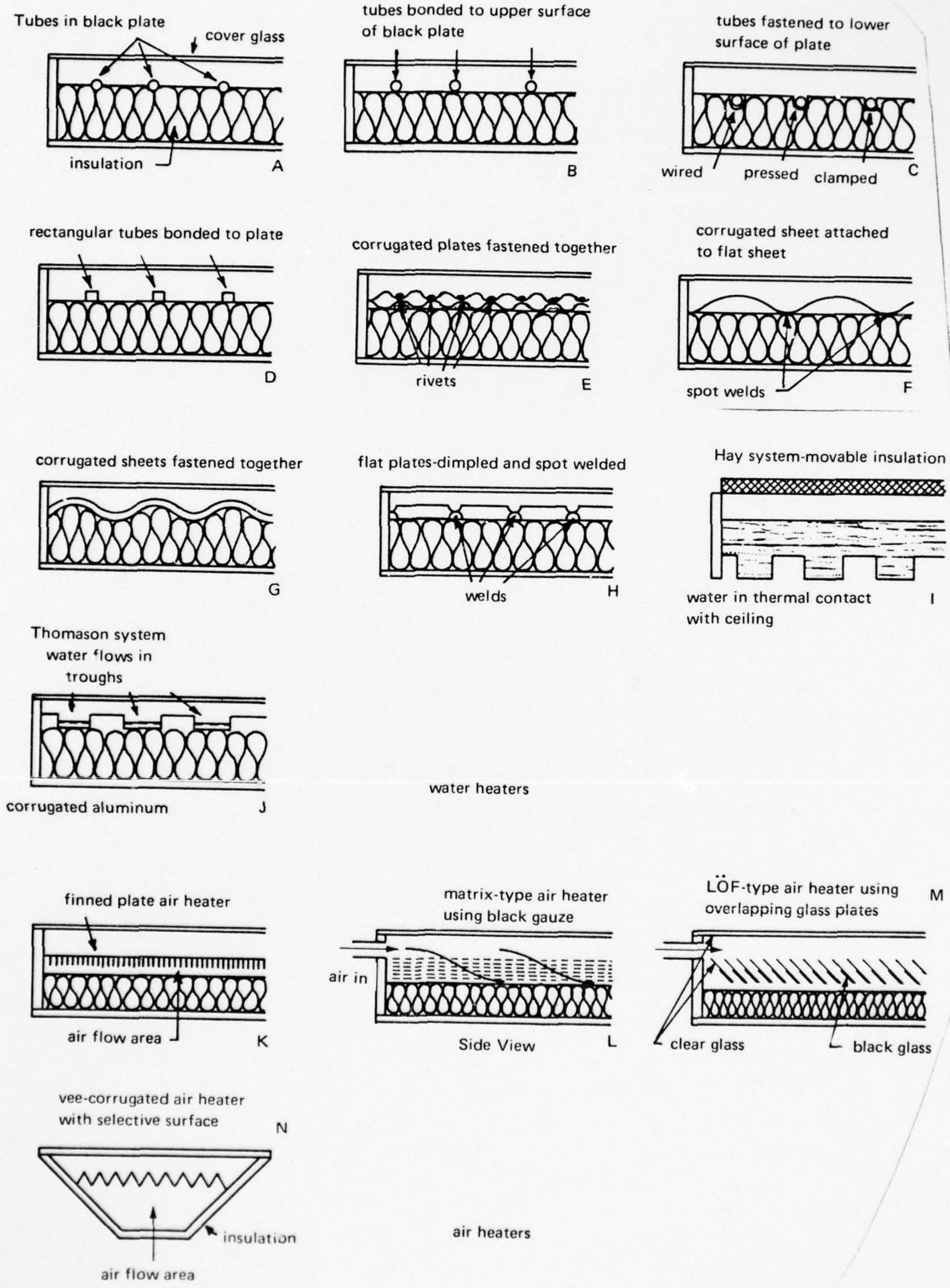

Figure B6. Various cross sections of solar collectors

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IDENTIFICATION OF ALTERNATIVE POWER SOURCES FOR DREDGED MATERIA--ETC(U)
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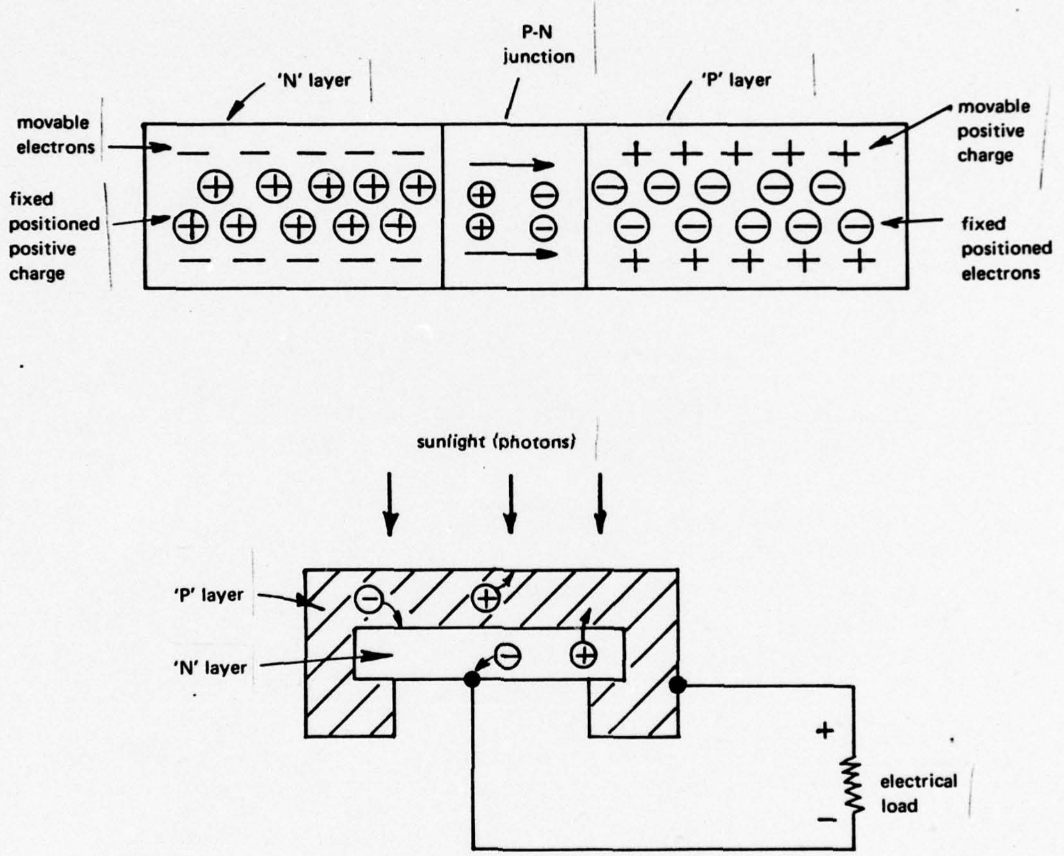

Figure B7. Typical photovoltaic solar cell

APPENDIX C: HYDRAULIC POWER ANALYSIS METHODOLOGIES AND CONVERSION SYSTEMS

Analysis Methodologies

Wave power

1. The potential-energy-derived portion of the available wave power (the rate of transfer of potential energy when waves fall from above the still water level to below it) may be expressed as:

$$\frac{W'\rho_w g^2 T' H_s^2}{64\pi} \qquad \text{(C1)}$$

where W' = width of wave front

ρ_w = mass density of fluid (2 $lb\text{-}sec^2/ft^4$ for seawater)

g = acceleration of gravity

T' = wave period

H_s = significant wave height, the average height of the highest third of the waves

2. The total power, including that from the kinetic energy of the water in orbital motion under the wave, is twice the power from the rate of change of potential energy.[22] Therefore, for a unit width (1 ft) of wave front:

$$P_{w'} = 0.028\ H_s^2 T' \qquad \text{(C2)}$$

where $P_{w'}$ = power per foot of wave front width, kw

H_s = significant wave height, ft

T' = wave period, sec

3. The power that can be converted by a wave power device is equal to the total power $P_{w'}$ multiplied by the overall efficiency η.

Current power

4. The power potential of water current P_C may be expressed as:

$$P_C = \frac{A'\gamma v^3}{2g} \quad \text{(C3)}$$

where A' = the projected (in the current direction) area

γ = weight density of fluid (62.4 lb/ft^3 for fresh water and 64 lb/ft^3 for seawater)

v = current velocity

g = acceleration of gravity (32.2 ft/sec^2)

This formulation assumes no significant elevation difference between the inflow and tail water. This assumption is generally valid for dredged material processing sites.

5. Most natural water current velocities decrease with depth. Offshore, where this decrease is fairly linear below the turbulent region near the surface, the average current speed over the depth of the submerged power plant runner may be used in the above equation to estimate the power potential. This simplification results in a conservative power estimate 5% to 10% too low.[17] In other water bodies in which current speeds are not significantly influenced by the tides, the same approach (i.e., averaging the current speed between the top and bottom of the runner) is adequate, provided the reduction in current speed with depth can be considered linear, or nearly so.

6. In water bodies with tidal influence, the current speed varies with the tide from a maximum in one direction at ebb to a maximum in the opposite direction at flood. An estimate of the annual average power level for a tidal current power system at a site with high tidal currents was made by Heronemus et al.[23] These authors assumed that equipment can be built which (a) recovers energy from currents in both directions and (b) shuts off at a current velocity of about 2.1 knots. They used the

tidal current predictions published annually by the National Ocean Survey (NOS). The reader is referred to the original reference for a complete description of this analysis methodology.

7. Potential current power can be estimated using the above techniques for any site and using, for example, the data given in Table D3. The validity of these estimates is clearly dependent on the accuracy of the current speed information, which should be from points as near as possible to the locations and depths where the power generation equipment will be used. Suitable data are frequently not available for the specific site and depth of interest because (a) the surface currents are those most frequently measured or predicted and (b) surrounding landforms and the bottom significantly affect currents — tidal currents, in particular.

8. An example of a site where published data on surface currents were useful in making an estimate of power potential is Nobles Island (north of New Hampshire). Heronemus et al.[23] were able to use tidal current predictions here because the site has water depths as great as 60 ft and indications of peak current influence down to the bottom. On this basis it was assumed that a uniform current velocity distribution exists down to 25 ft. It was also possible to lay out on a chart a 100-ft-wide path in the river far enough from land that a uniform current across the path could be assumed. Therefore, a 30-ft-deep, 80-ft-wide current power system could be designed for this site using available local source data. Unfortunately, not many sites are as ideal, so current measurements must be made before power potential can be estimated.

Descriptions of Conversion Systems

Wave power systems

9. Over 50 patents have been awarded since the turn of the century for devices to extract energy from the waves.[24] Only those devices intended to provide power to shore are of interest here. These devices seek to extract energy from the following sources:

A. The surge of water up the beach caused by waves,

B. The orbital water particle motions under the waves,

C. The vertical motion of the surface of the waves, and

D. The pressure changes below the waves.

10. The surge system, Type A, requires storage of water to the height of the waves in a lagoon on land into which the surging water spills.[25] One concept of this type calls for a converging channel through the surf zone that would concentrate the waves so that a head of water is maintained in a pond at the shore end of the channel by the net momentum transport of shoaling and breaking waves.[11] The stored water then runs back to sea level through a turbine. This type of wave power system requires the ponding of large amounts of water on land; natural basins, or vacant land on which artificial basins can be constructed, are generally not available at processing sites. Consequently, this type of wave system is not a good option for powering equipment for processing dredged material.

11. The orbital motion system, Type B, has received much attention recently. It is a rocking vane device that is claimed to be highly efficient.[25] Unfortunately, this system is quite large and must be free floating. Canney[26] holds no hope for such a system primarily because its dimensions must be carefully controlled to match the wave environment. Thus, Type B systems are not considered promising for providing the relatively small power requirements of dredged material processing operations.

12. The surface motion system, Type C, operates near shore and usually involves a moored floating object that operates a generator onshore through a submerged linkage. Such a system can be fabricated simply and operated with available hardware and conversion equipment. However, the problems of a float on the turbulent ocean surface and moving parts in contact underwater are great. Some of these problems are alleviated by a system that replaces the moored buoyant float with a weight suspended from a shore-based boom and puts the linkage system

onshore.[27] Unfortunately, this system must be used at a site with a very short horizontal tidal shift to minimize the boom length.[26] This shoreline system's vulnerability to storms will result in much maintenance and repair, and capital cost of a system to suspend heavy weights from shore out over the waves would probably be very high. Wave motion in the horizontal plane will distort the desired vertical action of the suspended weight.[26] Further refinements of Type C wave power systems may relieve some of the drawbacks mentioned above, but at present such a system is not a suitable power source for a dredged material processing operation.

13. A pressure system, Type D, may be moored to the seafloor or mounted directly on it. In either case the device is below the water surface in a relatively calm and less corrosive environment. A prototype of a moored wave power device was tested and found to have an efficiency of 33%.[28] A bottom-mounted system uses bellows on the seafloor to apply the pressure of passing waves to the pumping of a hydraulic fluid to an accumulator and generator onshore. One system of this type uses pliable rubber-like strips filled with hydraulic fluid and encased in concrete troughs.[29] This system was tested on a small scale; it was claimed that almost all of the pressure change from the waves was converted to usable energy.[29] The simplicity of this device and its high efficiency are definite advantages, but maintenance might be troublesome.[26] Another disadvantage with this system is that it might cause accelerated beach erosion and deposition.

14. Although none of the wave power system types above is without drawbacks, the Type D stands out as the more viable as a power source for dredged material processing operations. As with most alternative power systems, more development is required. The design criteria (as stated in Reference 28) for wave power systems should be:

"1. The device must operate beneath the sea surface.

2. It must have a reliable lifetime of two or more years.

3. It must be composed of the smallest possible number of moving parts.

4. All barriers against seawater penetration must be positive; no reliance upon working seals, rotating or reciprocating.

5. No operating parts shall be exposed to, or extend into, seawater.

6. The unit shall be composed, insofar as possible, of components commercially available, of proven long-life reliability.

7. The configuration must be compact and rugged.

8. The unit must produce usable power under ordinary moderate sea state conditions."

Current power systems

15. The momentum exchange devices that have been considered for the conversion of the energy in natural water currents to usable power are: (a) horizontal axis turbines with the axis parallel to the current flow, like the Kaplan turbine or open propeller; (b) horizontal axis turbines with the axis perpendicular to the current flow, like the water wheel or Savonius rotor; (c) vertical axis turbines, like the Voith-Schneider propeller; and (d) others, like an invention using a series of parachute drogues.[16]

16. Detailed analyses were made by Sheets[17] for the Kaplan turbine, open propeller, and vertical axis turbine when used underwater in a nearly constant velocity current and by Heronemus et al.[23] for the open propeller and Savonius rotor when used at the water surface for tidal river currents. Sheets judged the vertical axis turbine superior for his application, and Heronemus et al. favored the Savonius rotor for their application.[23] These preferred current power systems are described in the following paragraphs, based on the work of References 17 and 23, respectively. Sheets considered the water wheel for submerged application and found it inferior to the other turbines he considered, but the water wheel is included in the following discussion as a potentially useful device when used at the water surface.

17. Vertical axis turbine. A vertical axis turbine is shown in Figure C1. Advantages of such a turbine for conversion of water current energy include:

- a. Neither the platform nor the turbine assembly has to be rotated relative to the current flow direction.
- b. No structure other than the blades is in the way of the current flow through the turbine runners.
- c. The turbine runners can be designed to account for current velocity differences between the top and bottom of the blades.[17]

18. The turbine has the following disadvantages:

- a. Reasonable estimates of water current velocities and distribution with depth (hopefully measurements) are required for design.
- b. The turbine must be larger than either the Kaplan turbine or open propeller for the same flow velocity.
- c. The design for reliable blade adjustment to account for vertical flow velocity gradients is complicated and the fabrication expensive.[17]

19. Savonius rotor. The Savonius rotor was developed for the measurement of water currents. This rotor is usually oriented vertically for measurement, but for extraction of current energy a horizontal orientation is considered, as shown in Figure C2. Some of the pros and cons of this rotor as a water current energy conversion mechanism are given below. Its advantages include:

- a. Its simple geometry makes it relatively inexpensive to fabricate.[30]
- b. Operation is possible with currents that reverse direction.[23]
- c. Operation does not require the damming of a water source.[23]

20. The Savonius rotor has the following disadvantages:

- a. It lacks radial symmetry so the torque is not steady but varies as the rotor turns.[30]
- b. Design of this water surface penetrating system must be very sensitive to corrosion and biofouling.[23]
- c. When in the horizontal configuration shown, the rotor cannot efficiently extract energy from current in directions other than perpendicular to the axis.

21. Water wheels. Water wheels (Figure C3) were the traditional source of low power systems for centuries. Such a current power device has the following advantages:

a. No research and development is required to make the water wheel an effective water current energy extraction device.

b. The fabrication and maintenance are not complex.

22. The disadvantages are:

a. A very large rotating structure is required above the relatively small immersed paddles.

b. Water flow in only one direction is required.

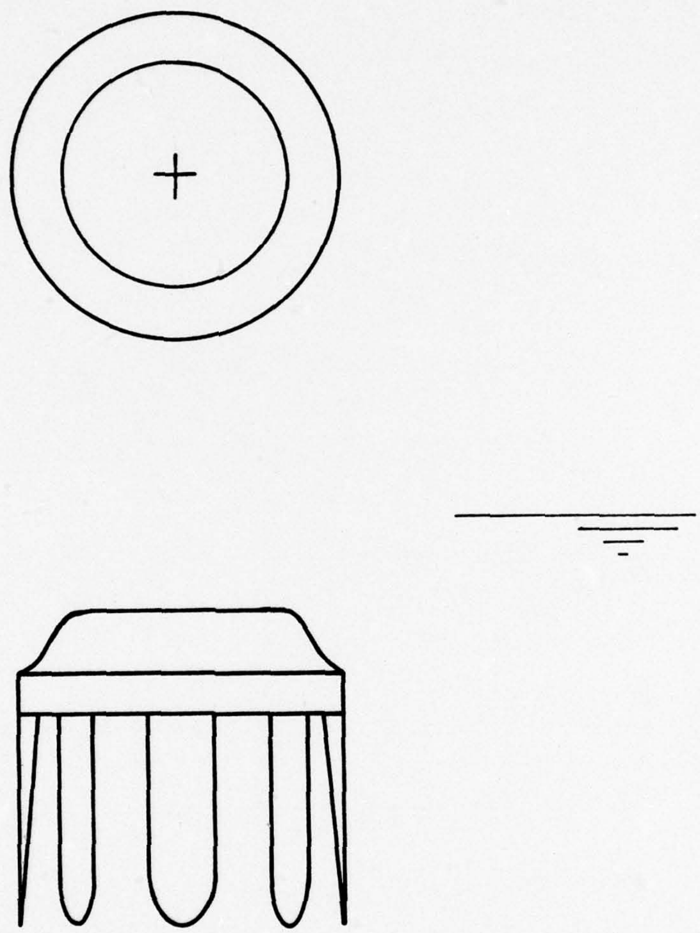

Figure C1. Vertical axis turbine based on work by Sheets[17]

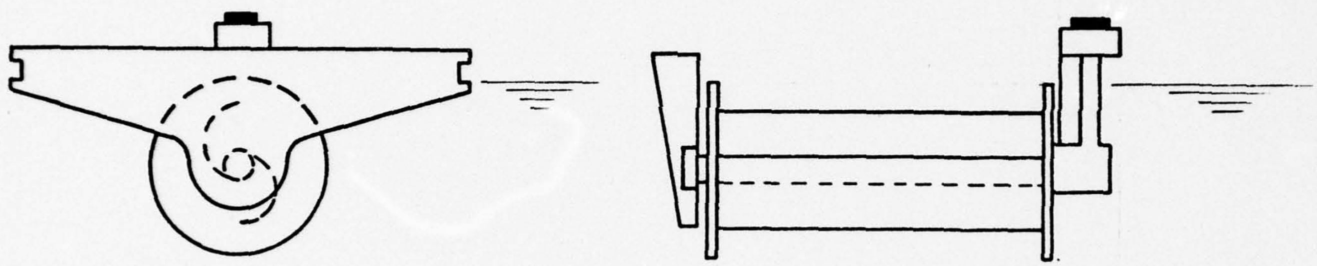

Figure C2. Savonius rotor based on work by Heronemus et al.[23]

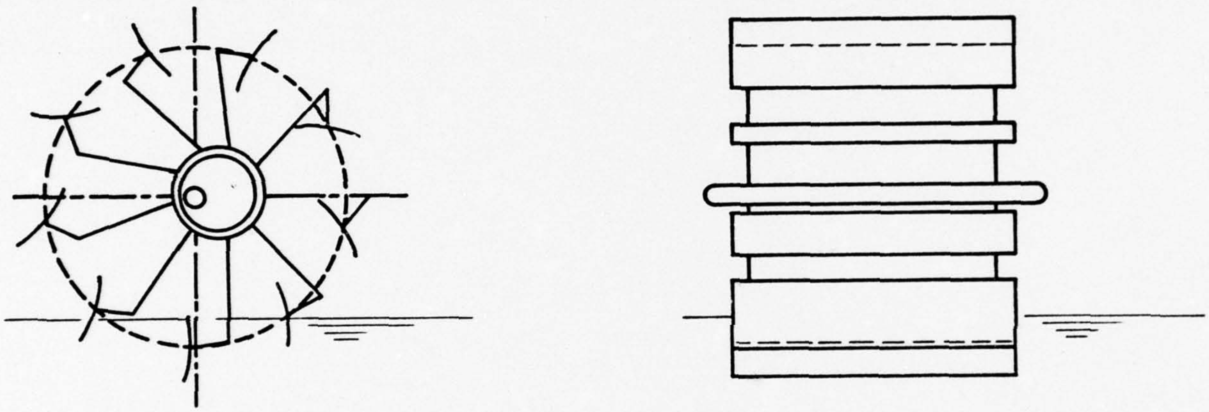

Figure C3. Water wheel based on work by Sheets[17]

APPENDIX D: DATA AND POWER POTENTIAL FOR SELECTED LOCATIONS

Wind Power Potential

Parametric plots

1. The performance curves for Elektro wind machines are shown in Figure D1. Based on the performance curve data, the power coefficients C_p, as functions of windspeed V, were obtained for all the Elektro units and are given in Table D1 for later use. The detailed data on the performance of the Aeromotor pumping unit are not available.

Windspeed and power duration curves

2. The windspeed V as a function of time t is not readily available from the existing data. As discussed in Appendix A, the wind data documented as a frequency of windspeed show the percentage of time (a year or a month) the windspeed was between certain values. The available data must, therefore, be reduced to the speed duration plot as follows.

- a. Starting with the zero windspeed, determine the percentage of time the windspeed is above a certain predetermined value. For instance, for 100% of the time, windspeed is above zero; this gives one point on the speed-time chart.
- b. Next, determine from the wind data the percentage of time speed is above a given value and plot it on the chart. A smooth curve through the points renders the speed-duration curve for a location. The windspeed-duration curves, each with a duration of 1 year for each site, were drawn using the annual average data.
- c. Next, the wind-power duration curve is derived from the speed duration simply by cubing the ordinate (i.e., the windspeed V) and multiplying it by the factor $(1/2)\rho A$ to obtain the power available in a column of air flowing through given disk area A.

The power duration curves, each with a duration of 1 year for each site, were prepared for later use. Both the windspeed and the power duration curves for each of the nine selected sites are shown in Figures 3 through 11. For simplicity, the disk area for the calculations was taken to be 100 sq ft; thus, the ordinate of the power duration curves in the above figures is the available power per 100 sq ft of the disk area. Also

prepared for comparison was the total available energy per 100 sq ft of the disk area at each site for a duration of 1 year, or 8760 hours; the results are shown in Table D2, which also gives the annual average windspeed at each site. Based upon the results of Table D2, Buffalo, Galveston, and Seattle show an excellent potential for windpower conversion. Norfolk, Detroit, Mobile, and Philadelphia have an average potential for wind energy, but Portland (Oregon) and Savannah (Georgia) show a relatively poor promise of wind energy. In summary, it can be stated that the windspeed duration and, hence, the corresponding power duration curves are useful tools in readily assessing the wind potential of a given site by simple calculations.

Solar Radiation Potential

Use of solar data

3. The term "solar radiation," is synonymous with the commonly accepted term of solar insolation and refers to the amount of sun energy received at the earth's surface as terrestrial solar energy.

4. Most solar radiation is measured with a horizontally positioned instrument called the pyranometer, which measures both the direct and diffuse components of the sun's energy. These data are recorded on a daily (and in some cases, hourly) basis in units of the langley (ly).*

5. Data on the average daily terrestrial solar energy received on a horizontal surface are of limited direct use in many solar energy conversion applications. What is sometimes more importantly desired are: (a) hourly solar radiation data — for hourly evaluation of particulars (system efficiency determination) of a solar energy conversion process; and (b) inclined receiving surface solar radiation data — for selection of optimum inclination or determination of energy received on a constrained receiving surface. Figures D2 and D3 show the typical daily distribution of solar radiation on clear days in the months of

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* A langley is equivalent to a gram calorie per square centimetre, or, in more common notation, equal to 3.687 Btu/ft^2.

January and June, respectively; Figure D4 depicts the typical yearly distribution of solar radiation for various receiving surface inclinations. The following discussion allows for estimating the hourly and inclined receiving surface solar radiation data from existing data.

6. Solar time. The hourly time values referenced herein refer to solar time, which basically accounts for the orbital factors of our earth and may vary from local standard time. The adjustment for converting solar to standard times is made by the following relationship:

$$\text{Solar Time} = \text{standard time} + \text{TA} + 4(\text{Meridian} - \text{Longitude})$$

where Standard Time = local clock time at location of interest (adjust for daylight savings time, if applicable)

TA = time adjustment, min (see Figure D5)

Meridian = standard meridian of time zone, deg West (see Figure D6)

Longitude = longitude at location of interest, deg West

7. Length of day. The length of day (sunrise to sunset) varies throughout the year and with geographical latitude.

8. Hourly solar radiation. The amount of solar radiation received on a horizontal receiving surface and available during various hours of the day is a percentage of the total daily solar radiation for various lengths of day. This information is most useful for locations where day-long clear sky conditions prevail; for overcast sky, these data are less valid.

9. Inclined receiving surfaces. Many methods have been proposed for estimating the amount of solar radiation, on inclined south-facing surfaces, from various known parameters. The method employed herein basically follows a rationale set forth in Reference 31. The conversion of "horizontal" solar radiation data to "inclined" solar radiation is made by the following relationship:

$$SR_i = (SE_h)(RA)$$

where SR_i = Average daily solar radiation received on a south-facing surface (angle from horizontal) in ly/day

SE_h = Average daily solar radiation received on a horizontal surface, ly/day

SE_o = Average daily extraterrestrial solar radiation received on a horizontal surface, ly/day

RA = SR_i/SE_h ratio at given latitude, month, receiving surface inclination, and SE_h/SE_o ratio.

Data will be found in Reference 32. An example follows.

EXAMPLE

Location: San Antonio, Texas

Latitude: 29.5^o N

Longitude: 98.5^o W

Q. What is the average daily amount of solar energy received on a horizontal surface in the months of February and September?

A. February = 347 ly/day (1278 BTU/ft^2-day)
September = 493 ly/day (1818 BTU/ft^2-day)

Q. What is the solar time at 1:00 p.m. standard time on September 15?

A. Standard Time = 1:00; TA = 5 minutes (see Figure D5);
Meridian = 90 degrees (see Figure D6); Longitude = 98.5 degrees (see input data)
Solar Time = 1:00 + 5 min + 4(90-98.5) = 1:05 - 34 min = 12:31 p.m.

Q. Assuming clear-sky conditions, how much solar radiation falls on a horizontal surface between 1:00 and 2:00 p.m. in September?

A. Length of day is approximately 12.2 hours
Solar Radiation = 12.4% of total daily input of 493 ly/day

Q. How much daily solar radiation falls on a 30-deg south-facing surface during the month of September?

A. SE_o = 786 ly/day (30 deg latitude)
SE_h = 493 ly/day

$SE_h/SE_o = 493/786 = 0.63$

RA = 1.10 (30 deg latitude, 30 deg, Sept)

$SR_i = (SE_h)(RA) = 493$ ly/day (1.10) = 542 ly/day

Hydraulic Power Potential

Data

10. Table D3 furnishes the local source data for hydraulic study for nine sites.

Parametric plots

11. Figures D7 to D9 are sizing and performance parametric plots for current power systems. These plots are intended to show the variation of output power with the most frequently measured characteristics of currents.

12. Figures D7 to D9 on the unidirectional current power system show the output power of devices of this type as a function of current speed. These plots are applicable to the size proportions and efficiencies given on the figures for vertical axis turbines, Savonius rotors, and waterwheels.

13. Parametric plots of tidal current power are not included because there is no common parameter that may be portrayed as a function of output power at any site. Furthermore, the energy available in the tidal currents at eight of the nine sites is minimal, and good data near enough to the ninth are not available.

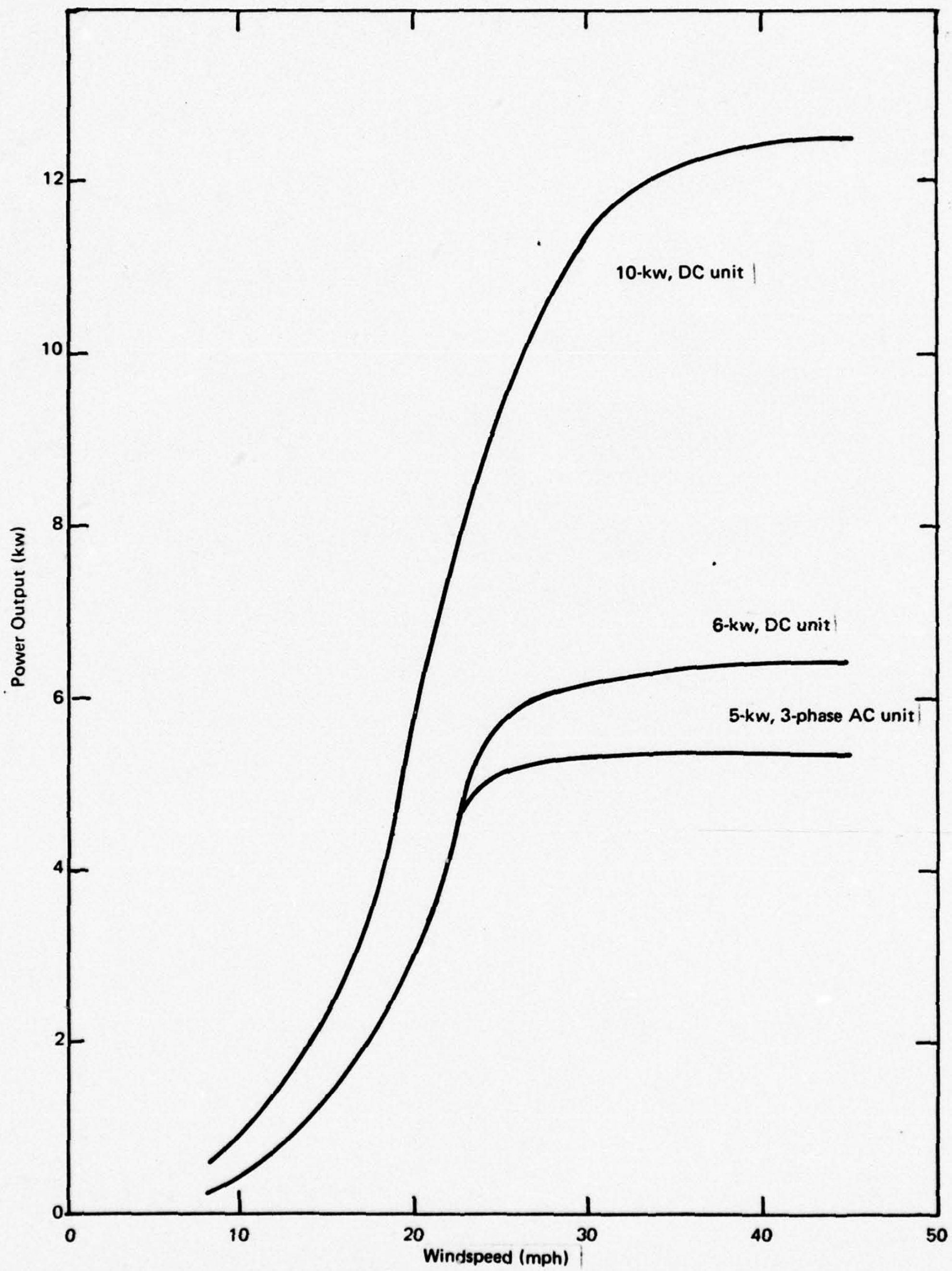

Figure D1. Power versus windspeed characteristics of Elektro wind generators

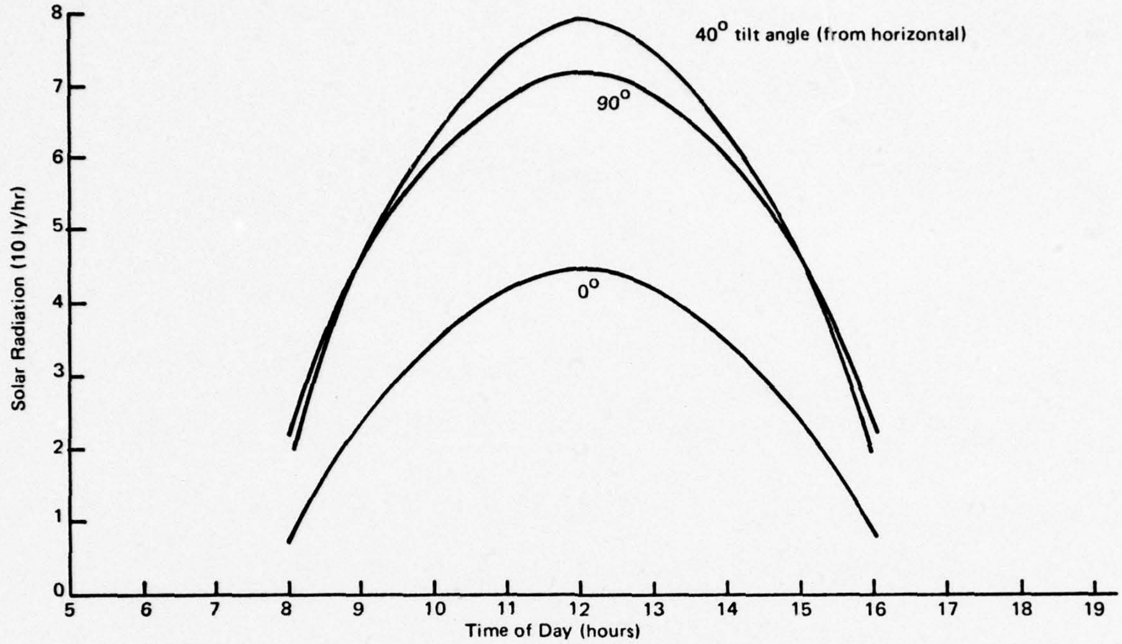

Figure D2. Average hourly solar radiation on tilted surfaces at $40^{\circ}N$ latitude in January

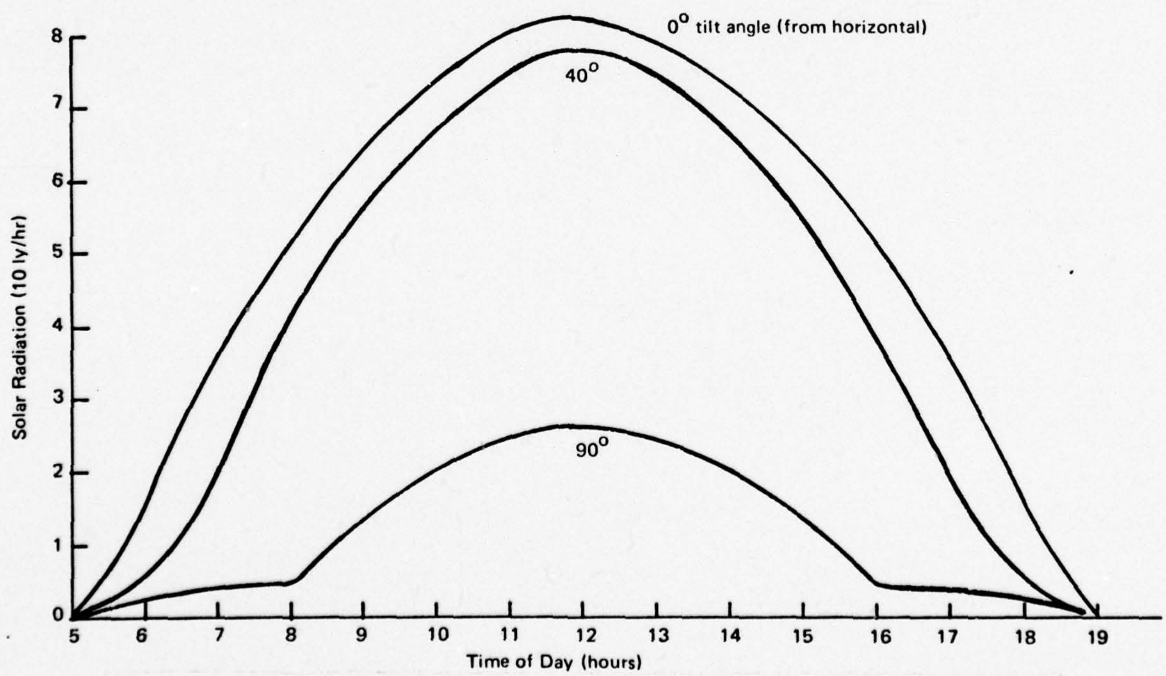

Figure D3. Average hourly solar radiation on tilted surfaces at $40^{\circ}N$ latitude in June

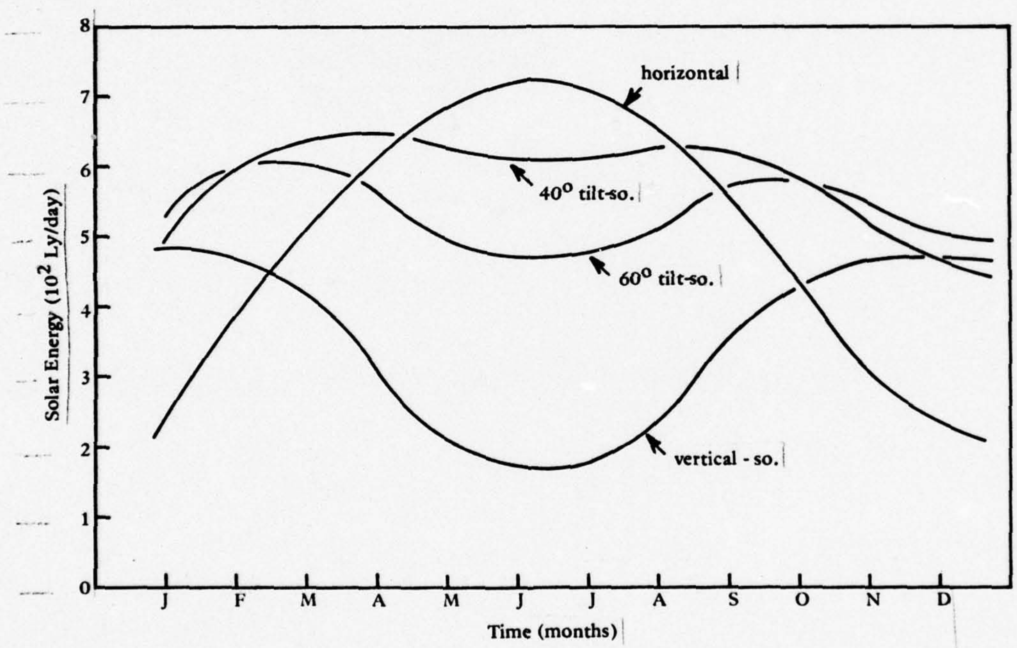

Figure D4. Energy received on tilted surfaces at 40°N latitude

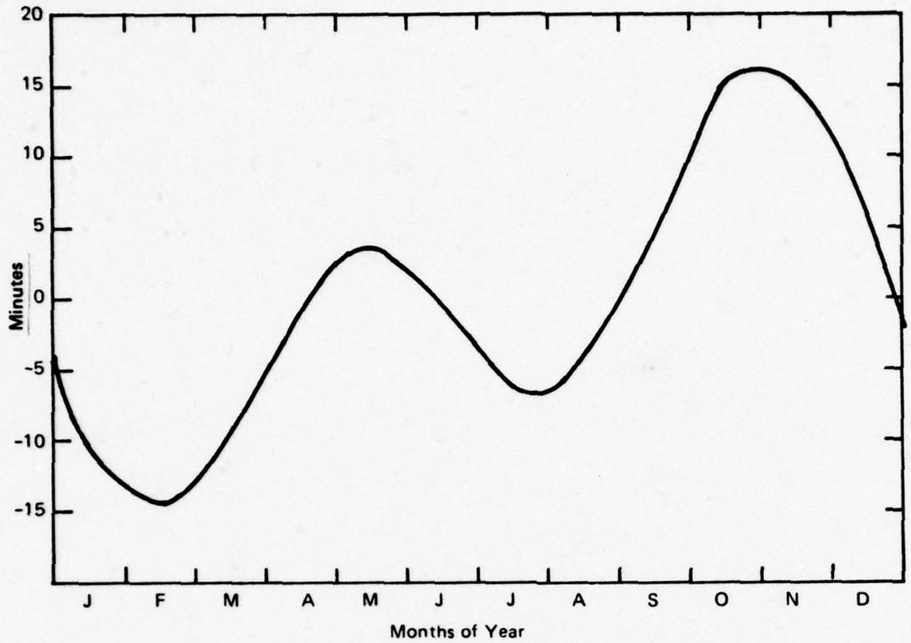

Figure D5. Graphical display of the equation of time

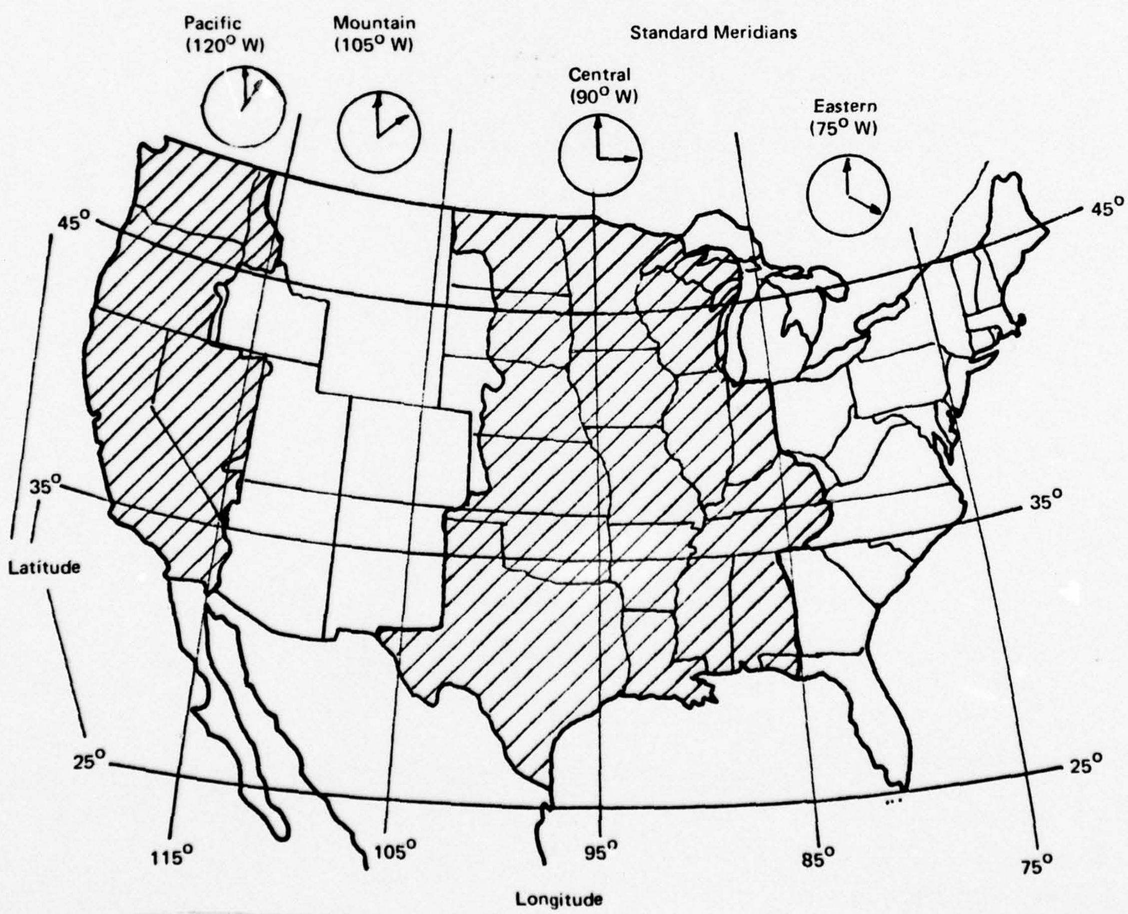

Figure D6. Latitude, longitude, and time zones of United States

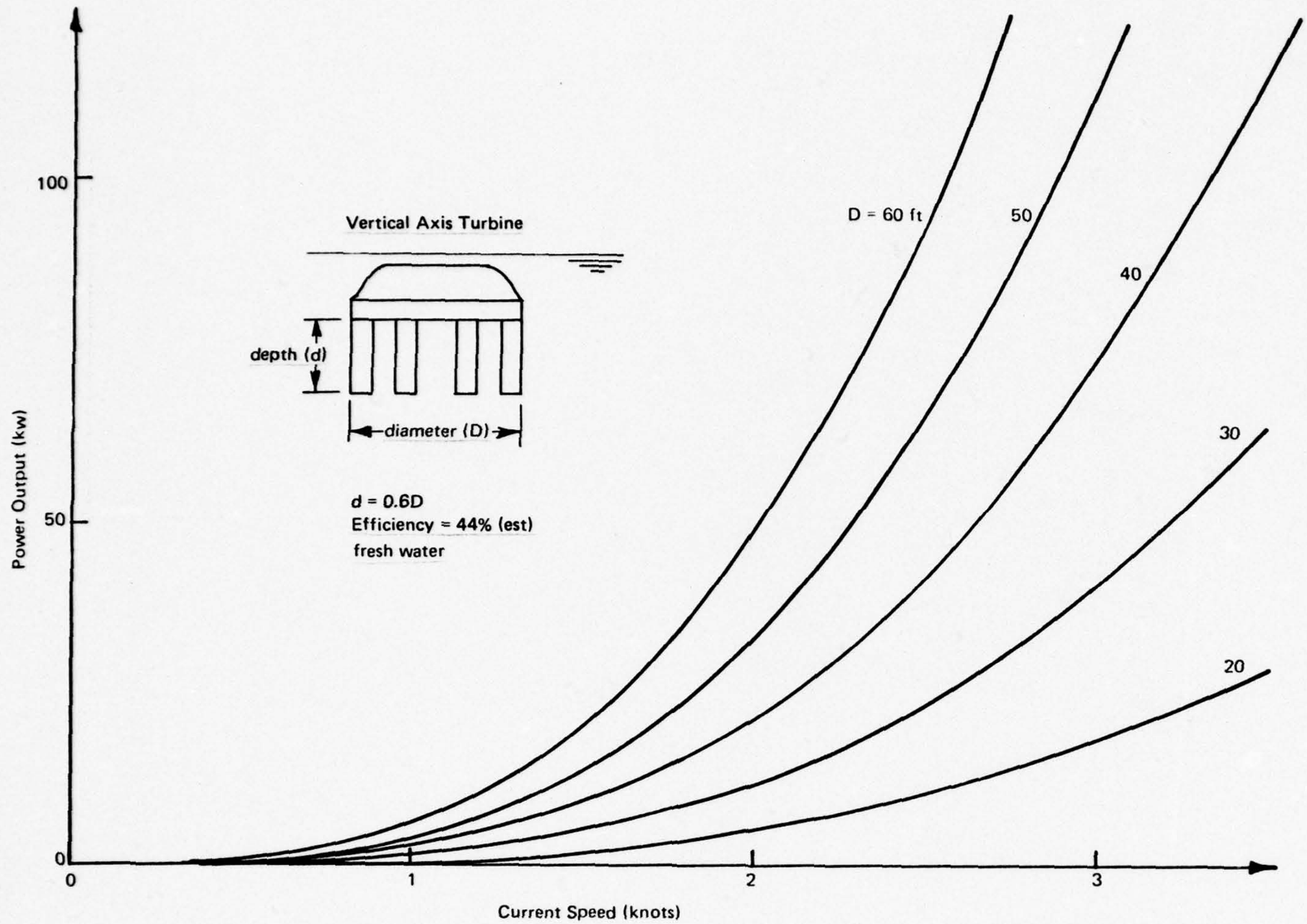

Figure D7. Unidirectional current power production — vertical axis turbine

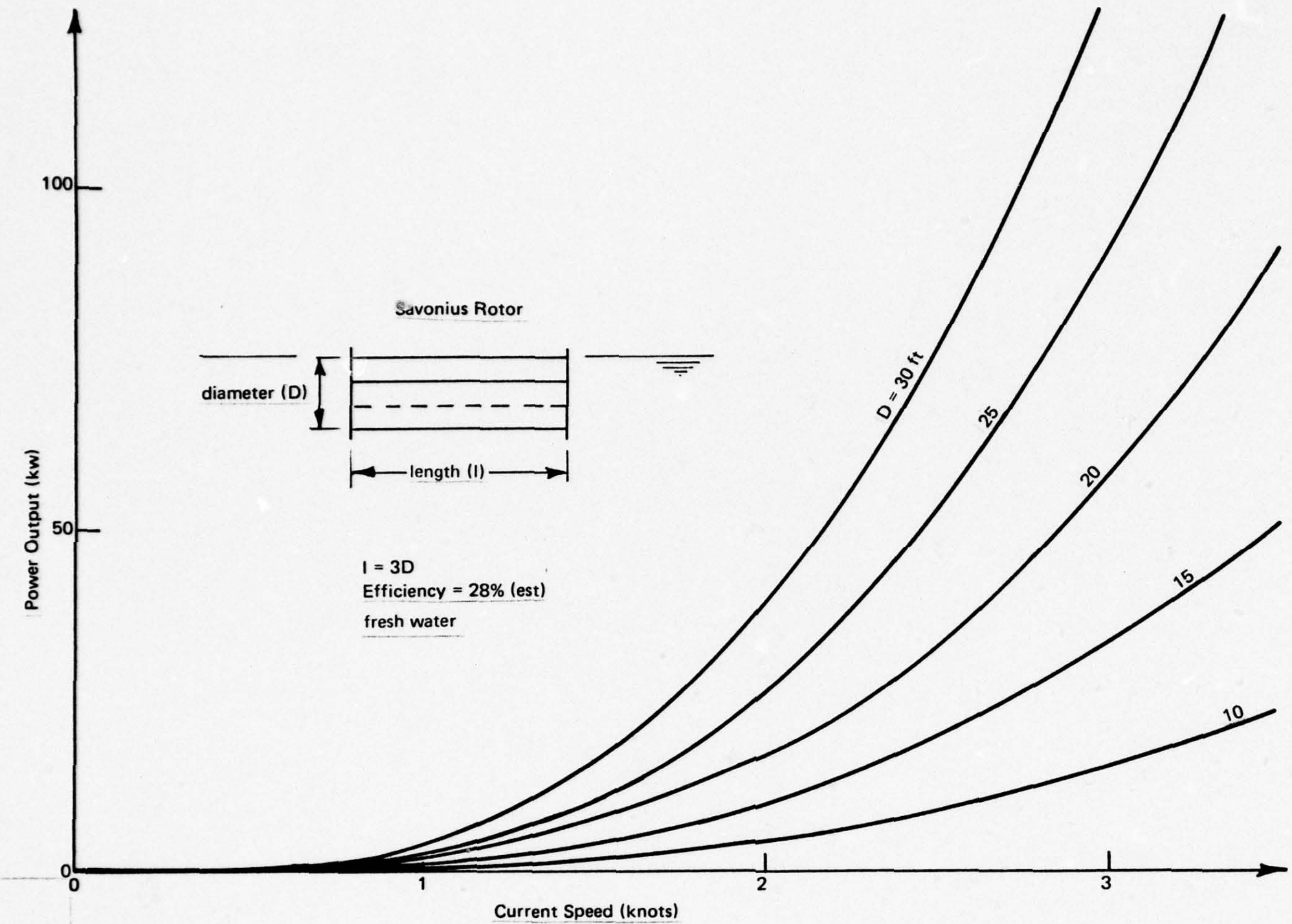

Figure D8. Unidirectional current power production — Savonius rotor

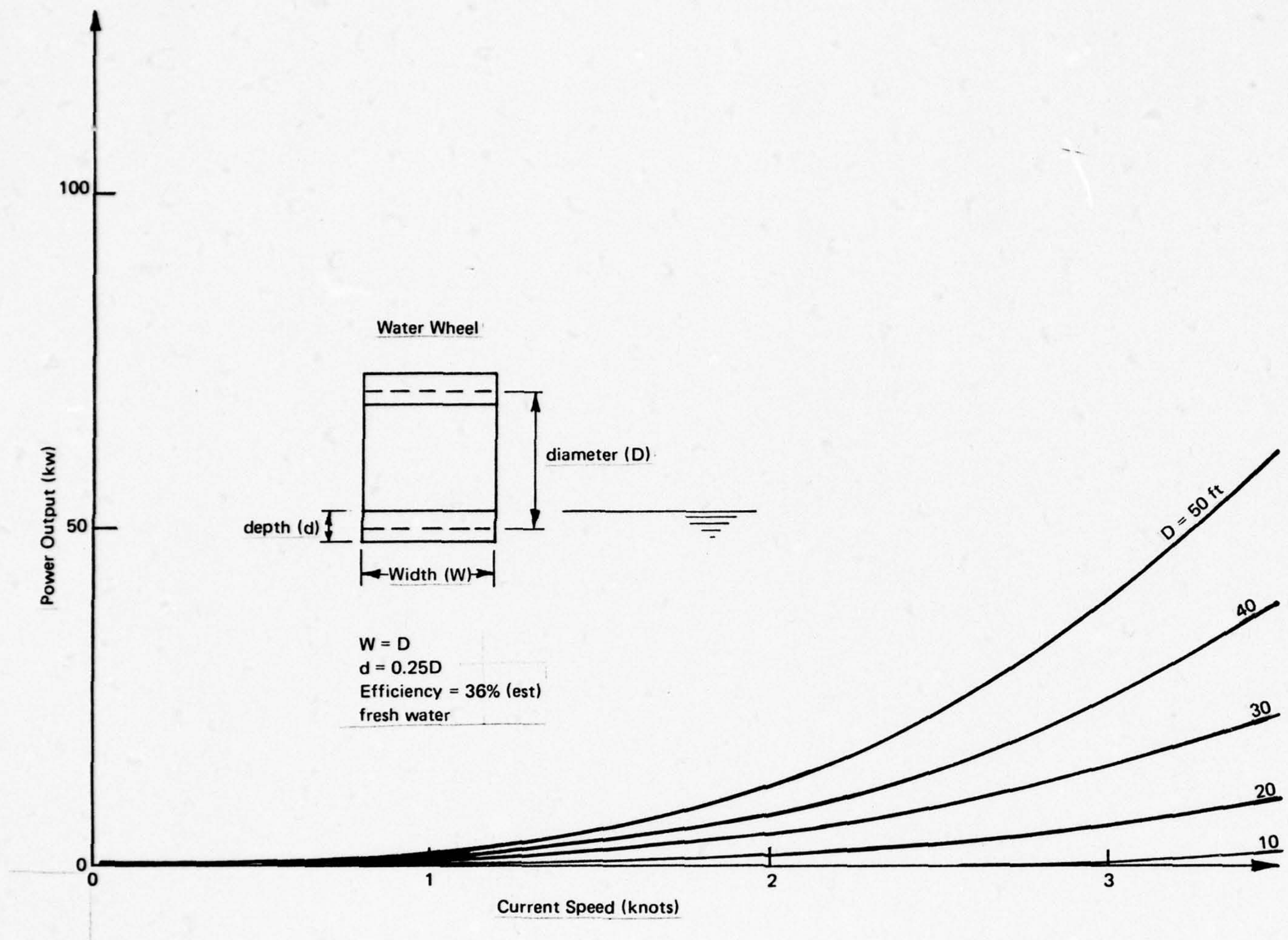

Figure D9. Unidirectional current power production — water wheel

Table D1

Power Coefficient C_p Shown as a Function of Windspeed V for the Elektro G.m.b.h. Wind Machines

Windspeed (mph)	Power Coefficient		
	Elektro 6-kw DC	Elektro 5-kw, 3-Phase, AC Unit	Elektro 12-kw AC Unit
0	0	0	0
3	0	0	0
7	0	0	0
10	0.443	0.443	0.443
12	0.417	0.417	0.417
15	0.390	0.390	0.390
18	0.376	0.376	0.376
23	0.370	0.370	0.370
24	0.343	0.343	0.343
26	0.307	0.260	0.307
27	0.288	0.232	0.267
32	0.175	0.148	0.200
38	0.106	0.090	0.123
46	0	0	0

Table D2

Available Energy Per 100 sq ft of the Disk Area in 1 Year (8760 hours) for the Nine Selected Sites

Location	Annual Average Windspeed (mph)	Total Available Energy Per 100 sq ft of the Disk Area in 1 Year (kw-hr/100 sq ft)
Buffalo, New York	12.4	16,634
Galveston, Texas	12.5	14,735
Seattle, Washington	10.7	11,498
Norfolk, Virginia	10.2	10,121
Detroit, Michigan	10.3	9,374
Mobile, Alabama	10.0	8,892
Philadelphia, Pennsylvania	9.6	8,481
Portland, Oregon	7.7	6,762
Savannah, Georgia	8.4	5,734

Table D3

Local Source Data for Hydraulic Study for Nine Sites

District	Site	Current			Waves		
		Data Location	Type	Speed, V (knots)	Data Location	Height, H (ft)	Period, T (s)
Philadelphia	Howell Cove Dike	Gloucester	tidal	$V_{max} = 2.2$ $V_{min} = 2.0$	not applicable	---	---
Galveston	Fort San Jacinto	Galveston Bay Entrance	tidal	$V_{max} = 2.3$ $V_{min} = 1.7$	offshore in gulf	$H_{ave} = 1$ to 5	$T_{ave} = 1$ to 5
Savannah	Andrews Island, Brunswick	Brunswick Riv off Quarantine *Dock (2 miles* downstream)	tidal	$V_{max} = 2.1$ $V_{min} = 1.3$	protected	---	---
Mobile	Blakely Island	Mobile River Entrance	tidal	$V_{max} = 0.7$ $V_{min} = 0.3$	protected	---	---
Seattle	Anacortes Harbor	Guemes Channel, West Entrance	tidal	$V_{max} = 2.1$ $V_{min} = 0.9$	protected	---	---
Portland	Price Island, Astoria	Glatsop Spit (22 miles dosnstream)	tidal	$V_{max} = 4.2$ $V_{min} = 3.6$	not applicable	---	---
Detroit	Diked Disposal Area, Toledo OH	Cherry Street Bridge (5 miles upstream)	wind dependent	$V_{max} = 2.7$ $V_{min} = 0$	Toledo	$H_{ave} = 1$ $H_{max} = 8$	$T_{max} = 5$ to 6

Table D3 (concluded)

District	Site	Current			Waves		
		Data Location	Type	Speed, V (knots)	Data Location	Height, H (ft)	Period, T (s)
Norfolk	Craney Island	Craney Island	tidal	$V_{max} = 1.2$ $V_{min} = 0.7$	protected	---	---
Buffalo	Cayuga Island	Niagara River (East of Grand Island)	Unidirec-tional	$V_{ave} = 1.5$	minimal	---	---

APPENDIX E: INFORMATION SOURCES

Wind Power

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* Until recently the principal source for obtaining solar radiation measurements was the National Weather Service at Asheville, N.C. These data are sparsely recorded, applicable only to horizontal receiving surfaces, and its credibility sometimes questioned because there was only limited interest in solar radiation measurements prior to the "energy crisis." Today, however, in addition to the National Climatic Center, the refinement of the Weather Service, and the expansion of its data acquisition program, there are other government agencies, numerous schools, solar energy related equipment manufacturers, utilities, and even individuals taking solar radiation measurements. It will take time for these new data sources to establish statistical recordings that can be utilized, but these new sources will eventually fill present data voids in both geographical location and receiving surface's orientation/inclination.

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